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G-G-23.

EXERCISES IN SURVEYING

FOR

FIELD WORK AND OFFICE WORK

WITH

QUESTIONS FOR DISCUSSION

INTENDED FOR USE IN CONNECTION WITH THE
AUTHOR'S BOOK

PLANE SURVEYING

BY

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PREFACE.

This book of exercises is intended for use in connection with the author's book on "Plane Surveying." Part I consists of exercises in field work grouped according to the nature of the work. Part II consists of exercises in office computations and in plotting. (See page 110.) The whole constitutes a thorough introductory course in fundamental principles and methods. So far as the author is aware, this is the first attempt to offer a collection of problems in both field work and office work, and the first book of exercises to be published for use in connection with a text-book.

The author is convinced from his own experience that the most effective course in field work is not that in which the chief aim is to make a complete survey of a more or less extensive territory. On the contrary, much time may be lost in undertaking work for which the student is not prepared, and still more may be wasted in requiring the student to repeat the same kind of work day after day merely to cover a given amount of territory. It is far better to begin with a systematic course of exercises which shall serve not only as a preliminary drill in the use of instruments, but also as a careful study of the various methods which underlie all surveying. Not only will the student be better prepared for subsequent courses in municipal, mining, railway and geodetic surveying, but the effect of such a thorough introductory course will be felt after graduation in whatever kind of surveying he may be engaged. For this reason such a course may well extend over the first two college years.

A feature of this book will be found in the questions suggested for discussion at the end of nearly every exercise. Some years ago the author adopted the practice of holding quizzes in the field in connection with each new piece of work. For example, an instructor has charge of a small squad of men to whom problems in chaining have been assigned. As soon as the work is finished, he gathers his men about him, and questions them on various matters pertaining to chaining, such, for example, as the use of the steel tape, the sources of error, different methods of doing the work just completed and the advantages and disadvantages of these methods. In some other part of the field another instructor may be holding a similar quiz on leveling or on transit work. These quizzes, if properly conducted, often develop into interesting discussions in which many important points are brought out that would entirely escape the student if he were merely required to do the field work assigned. Moreover, the student may be expected to take his text-book into the field with him, and to spend such spare time as he may have in looking up answers to questions which he knows will be asked at the end of the exercise. A great deal of the recitation work usually held in the class-room will be much more effective if it is transferred to the field in this way. If, however, it is found inexpedient to hold these quizzes and discussions in the field, the questions may still be used by the earnest student to develop his knowledge of the subject. They should prove particularly valuable to young men in practice who are seeking to perfect themselves in the art of surveying.

In most courses it probably will be found necessary to omit some of the exercises given in this book. It is suggested, however, that the student be held responsible for answers to the questions in the omitted exercises, and that, if possible, these questions be made a basis for class-room discussion.

Unless otherwise stated, all paragraph and page references are to the author's text-book and not to this book.

JOHN C. TRACY.

NEW HAVEN, CONNECTICUT.
June, 1909.

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Exercises in Plane Surveying.

PART I.

FIELD WORK.

GROUP E.

INTRODUCTORY EXERCISES.

This group of exercises, consisting principally of questions for class-room discussion, are intended to cover those fundamental principles and methods which the student should know before beginning field work. The exercise on single-stroke lettering is inserted for the benefit of students who have not had a systematic course in freehand lettering.

Exercise E–1.

Definitions, Fundamental Principles and General Methods.

Reference: Chapter I, pp. 1–8.

Questions: 1. What is meant in geodesy by the earth's surface? p. 1. 2. When is it necessary to make this distinction in ordinary surveying? 3. What is the shape of the earth's surface? 4. What is the average radius? 5. What is the difference in lengths between the long and short axes, expressed in miles? 6. What is meant by sea-level, and how can it be determined at any given place? 7. Define horizontal plane; vertical plane. 8. What is the difference between a horizontal plane and a level surface? 9. What is the significance of the two terms "plane" and "geodetic" as applied to surveying? p. 2. 10. What is the approximate curvature of the earth's surface per mile? 11. How large an area may be covered by the methods of plane surveying without involving appreciable errors? 12. Give the approximate difference in length between the arc on the earth's surface and a straight line. 13. What four kinds of measurements are made in plane surveying? (Illustrate by means of a sketch.) 14. If a farm is on a side hill, would a map of that farm show the actual area of the surface? 15. What are the units of linear measurement used in surveying in the United States? p. 3. 16. What are the units of angular measurement? 17. In making certain kinds of surveys, as for example, a survey for an architect, is it ever customary for the surveyor to measure in feet and inches? 18. What is a convenient method of converting hundredths of a foot to fractions of an inch? 19. From the table on page 650, change 6 feet 4⅛ inches to feet and decimals of a foot. 20. What is the standard yard? p. 3. 21. In this country where may a steel tape be sent to be compared with a standard length? p. 561. 21. What is the equivalent of one metre in feet? p. 3. 22. What is the equivalent of one vara in inches? 23. What other units of measurements are sometimes used? 24. Why was 66 feet adopted as the length of Gunter's chain? 25. How would you record eight chains, six links? p. 33, § 49. 26. Reduce sixty links to feet? 27. Explain the method of locating a given point with reference to two other points by linear measurements only. p. 4. 28. Explain two methods of locating a point by angle and distance. 29. Explain the method of locating a point by angles only. 30. Explain two other methods of locating a point. 31. Into what three parts may the work of a surveyor be divided? p. 5. 32. Of what does the field work consist? 33. Of what does the office work consist? 34. Name some of the important questions in surveying which arise in connection with field work. p. 6. 35. Explain by different illustrations how the purpose of a survey helps to decide some of these questions. 36. What can you say regarding limits of error and consistent accuracy? p. 7. 37. Upon what does speed depend? p. 8. 38. How does system in surveying diminish the chances of error?

Exercise E–2.

General Discussion of Errors.

Reference: Chapter II, pages 9 to 19.

Questions: 1. What is the true error of any measurement? p. 9. 2. Why is the true error never known? 3. In general, what are the three sources of error? 4. What are the three classes of error? 5. Explain carefully the difference between constant errors and accidental errors. p. 10. 6. Can the constant error involved in any measurement be reduced by repeating the measurement a number of times and taking the mean of all the measurements? 7. What is the object in repeating the measurements and taking the mean? 8. Give a few illustrations of what is meant by mistakes; accidental errors; constant errors? 9. Why may variations in sources of constant error be classed as accidental errors? p. 11. 10. How may constant errors from different sources tend to balance each other? 11. How may constant errors from the same source tend to balance each other? 12. Explain the difference between cumulative and compensating errors. 13. Explain the difference between discrepancy and error. 14. How can the discrepancy between two measurements be small yet the error large? p. 12. 15. What can you say as regards the elimination of constant errors? 16. How may mistakes be eliminated? 17. Illustrate how constant errors may be eliminated. 18. How may accidental errors be reduced? p. 13. 19. What can you say as regards the relative importance of errors from different sources? 20. What is meant by an appreciable error? 21. What is the most probable value of a quantity, when several measurements have been made of that quantity? 22. When the sum of several measurements should equal the exact quantity, how is the *true* error distributed? p. 14. 23. If the *true* error of a measurement is never known, how can the error of 1′ or 60″, in the illustration on page 14, Case 1, be called a *true* error? 24. Explain by illustration how the discrepancy should be distributed, when the sum of several measurements should equal some other measurement. 25. Why, in Case 2, p. 14, is the term "discrepancy" used instead of "error"?

Questions on the Method of Least Squares: 26. What use is made of the method of least squares? p. 15. 27. Upon what assumption is this method based? 28. How do the conditions in practice differ from those of the assumption? 29. What effect has this on a most probable value of a quantity as determined by the method of least squares, and how may the probable value be made to approach the true value? 30. Define residual; probable error. 31. In surveying, what use is made of most probable values; probable errors? 32. Illustrate how by comparing the probable errors of the means of two sets of observations, the precision of one mean may be compared with that of the other. p. 16. 33. Explain the use made of the probable error of a single observation. 34. How can the weights which should be given to different sets of observations be found from the probable errors? 35. Upon what three assumptions are the formulas for calculating probable errors based? p. 17. 36. What additional point should be kept in mind? 37. In order that probable errors may be of any significance, what precautions must be taken? (See Remark, p. 17.) 38. Two chainmen measure a line six times with the following results in feet: 314.124, 314.130, 314.133, 314.128, 314.136, and 314.131. Two other chainmen measure the same line with the following results in feet: 314.134, 314.124, 314.138, 314.122, 314.131, and 314.122. What is the relative precision of the work of the two pairs of chainmen? (See illustration, p. 19.) 39. An angle is measured with a transit eight different times. The degrees and minutes being the same but the seconds varying as follows: 20″, 40″, 30″, 10″, 20″, 50″, 30″, and 40″. The same angle was measured with another transit with the following result: 40″, 20″, 20″, 30″, 40″, 30″, 30″, and 40″. Other things being equal, which is the better instrument? What degree of precision may be expected for each instrument in measuring a given angle under conditions similar to those prevailing when the above angles were measured?

Exercise E-3.

General Discussion of Field Notes.

Reference: Chapter III, pages 20 to 30.

Questions: 1. What are field notes? 2. What can you say as regards methods of keeping notes? 3. Give general suggestions for keeping notes. p. 21. 4. Into what three parts may field notes be divided? 5. Give general suggestion for recording numerical values. p. 22. 6. Give general suggestions for making sketches. p. 23. 7. Give general suggestions concerning explanatory notes. 8. What style of lettering should be used? p. 24. 9. What is a good height for letters? p. 29. 10. How should the letters be spaced? 11. Give additional suggestions for taking notes. p. 29. 12. Discuss special directions for class work. p. 30.

Exercise E-4.

Single Stroke Lettering.

Reference: Article 38, pages 24 to 30.

Directions: In this exercise use a 4H pencil and smooth white paper with hard surface. Sharpen the pencil to a fine point. At first, draw a bottom guide line for letters; later, practice lettering without a guide line. In forming the various letters and figures pay particular attention to the direction and sequence of the strokes in each letter and learn the peculiar characteristics of each. The stem of a letter which extends above or below the body of the letter should not be made too long — a common mistake.

(*a*) Print the entire alphabet of lower case letters, grouping them in five groups : adgq, bp, ceos, hmnu, and fijklrtvwxyz. (See p. 25.) Repeat this exercise several times.

(*b*) Print the capital letters of the alphabet, grouping them as follows: EFHIKLMNTZ, AVWXY, BPR, CGOQ, and SJDU. (See p. 28.) Repeat this exercise several times.

(*c*) Practice making the numerals from 1 to 0. (See p. 27.)

(*d*) Rule bottom guide lines about a quarter of an inch apart, and print in single stroke lettering, with the letters spaced as closely together as possible, the introductory note on page XXVII.

GROUP C.

EXERCISES IN CHAINING.

The first six exercises of this group offer the student an opportunity to form correct habits in the use of the steel tape, and, by a study of the sources of error, to learn what precautions must be taken to attain a given degree of precision. The remaining exercises involve special problems in chaining, most of which are based on well known geometric constructions. If it is necessary to omit any of these latter problems in the field, the omitted problems may be given in the class-room as blackboard exercises, and the corresponding questions discussed by the class.

Exercise C–1.

Reading a Chain Tape.

References: Page 32, § 48; p. 33, § 50 (a) (b) (c) (d).

Equipment: Chain tape and chain pins.

Directions: 1. On a level piece of ground, stick two chain pins at random about 50 feet apart. 2. Measure the distance between these two pins to the nearest tenth of a foot. 3. Repeat the measurement, the two chainmen interchanging positions.

Questions: 1. Why should the chainman at the end of the tape make the final reading? § 50 (c). 2. Why should the other chainman read the number on each side of the required reading? p. 33. 3. What kind of tape may be used to render these precautions unnecessary? § 50 (d). 4. Does the surveyor use decimal parts of a foot or inches? p. 3. 5. When would it be desirable to use a tape graduated to inches? 6. Are linear measurements in surveying ever made along an inclined surface? p. 2. 7. What is the equivalent of one vara in inches? p. 3. 8. What is the equivalent of one meter in feet? p. 3. 9. What other units of measurements are sometimes used? p. 3. 10. Why was 66 feet adopted as the length of Gunter's chain? p. 3. 11. What is a convenient method of converting hundredths of a foot to fractions of an inch? p. 3. 12. What is the difference between Gunter's chain and an Engineer's chain? p. 559. 13. How would you record 10 chains 7 links? p. 33, § 49. 14. Compare the three kinds of tapes. p. 559. 15. What are the relative merits of a chain and a tape? Remark, p. 33. 16. Describe the different kinds of steel tapes, and the standard methods of graduating tapes. pp. 560, 561.

Exercise C-2.

Chaining Distances Greater than the Length of the Tape.

References: Page 34, § 50 (e) and (f), § 51 and § 52; p. 37, § 56, 1–12.

Equipment: Two range poles; steel tape and chain pins.

Directions: 1. Ascertain just what points to take for the ends of the tape. 2. Set two chain pins about 300 or 400 feet apart on comparatively level ground. 3. Chain the distance between these two pins. 4. Repeat the measurement, the two chainmen interchanging positions. By means of the tape tables on pages 48 and 49 ascertain whether the discrepancy between the two measurements indicates poor work or good work.

Suggestions: Special attention should be paid by the instructor to the method of sticking the pins as this is usually the source of greatest error on level ground. Insist on the use of signals, page 35, and caution men in regard to pulling up pins that mark the ends of a line.

Questions: 1. What is the approximate pull used in ordinary chaining? p. 42, § 65. 2. Why should the pins be stuck at right angles to the line? 3. How are the pins used to keep count of tape lengths? 4. How can the head chainman keep himself approximately in line? 5. In accurate work what precaution should be taken after each pin is stuck? p. 37, § 56 (12). 6. If there is a slight difference between the first and second measurements of the line, what is this difference called? p. 11, § 20. 7. If this discrepancy is small, is the error of chaining necessarily small? p. 11, §§ 20, 21. 8. If the tape used in measuring is too long or too short, is this a source of constant error? p. 10. 9. Are the errors from sticking the pins accumulative or compensating? p. 11, also p. 42, § 66. 10. If in lining in, pins are set as much as 6 inches first one side, then the other of the line, will the resulting error be comparatively large or small? p. 41, § 63, p. 51, § 76. 11. How may the error in chaining be expressed by a ratio? p. 39, § 58. 12. If a line is measured with a tape that is too long will the result be too long or too short, and what is the corresponding algebraic sign? p. 39, § 59. 13. What are some of the things a chainman should do? 14. What are some of the things a chainman should not do? p. 38. 15. If in chaining a line *AB* whose true length is 400 feet, the first pin is stuck 18 inches to the left of the line, the second pin 16 inches to the right, the third pin 24 inches to the right, what would be the difference between the true length and the measured length of AB, provided no other errors are involved? 16. If in measuring along a line the end of the tape should fall at a place where a pin cannot be stuck, as, for example, in the middle of a brook, how would you proceed?

Exercise C-3.

Chaining on a Slope.

References: Page 35, § 53.

Equipment: Steel tape, chain pins, range poles, plumb bob.

Directions: 1. Measure the distance between two points on a comparatively steep slope by the second method, page 36, working down hill. 2. Repeat the measurement, chaining again down hill, but the two chainmen interchanging positions. 3. By means of the tables on pages 48 and 49, ascertain whether the discrepancy between the two measurements indicates work that is excellent, good, fair or passable.

Suggestions: 1. Pay special attention to throwing the weight of the body against the arm in holding the down-hill end of the tape. p. 36. 2. If the pin is stuck upright it interferes with the plumb bob — one reason for sticking it in slanting at right angles to the line. 3. A common error is the holding of the down-hill end of the tape too low. The instructor, standing opposite the middle of the tape, should watch this at first. 4. Three men can work to much better advantage than two in chaining on a slope.

Questions: 1. Why is it better to chain down hill than up hill? 2. If a line is chained on the slope instead of in horizontal stretches, how may the result be corrected? Page 35, § 53 (a).

Exercise C-4.

Standardizing the Tape.

References: Pages 39–44 and p. 561.

Equipment: Steel tape to be tested; scale, spring balance, turnbuckles, thermometer, magnifying glass.

Directions: Assuming that a permanent standard has already been established, proceed as directed for "Testing the Tape," page 562. 2. Repeat the test two or more times.

Suggestion: Sometimes in place of a permanent standard such as that described on page 562, the tape is compared with a standard tape of known length, kept for that purpose.

FORM OF NOTES.

Tape Tested.	Observed Length.	Temperature.	Correction for Temp.	Corrected Length.

Questions: 1. What are the usual standard temperatures and standard pulls for a 100 foot steel tape? Pages 561 and 42. 2. What is the average change in length for each 15 degrees change in temperature? p. 40, § 62 (a). 3. What is the average change in length per 15 pounds pull? p. 43, § 69 (7). 4. Where can a tape be sent for standardizing? p. 561. 5. What are some of the conditions to be fulfilled in any device for standardizing tapes? p. 561. 6. What was the object in using a steel strip for the standard of the Boston Water Works? p. 562. 7. A line measured with a 100 foot tape is found to be 826.34 feet long. What was the true length of the line, (a) if the tape was 100.024 feet long? (b) if the tape was 99.87 feet long? 8. Required to lay off the distance of 784 feet with a tape (a) 100.04 feet long; (b) 99.9 feet long.

Exercise C-5.

Experiments with a Steel Tape.

References: Page 40, § 62 (c), p. 41, § 64.

Equipment: Steel tape, scale, spring balance, turn-buckles, thermometer, magnifying glass, 2 plumb bobs.

Directions: 1. Perform the experiment of § 62 (c), p. 40. 2. Test the length of a tape first under a 12 pound pull, then under a 20 pound pull. Repeat several times. 3. With the ends of the tape supported a short distance above the floor or ground, the rest of the tape being unsupported, find the tension required to make the tape of standard length. Use plumb bobs to mark the ends of the tape and turn-buckles to hold the tape steady at the standard pull.

Questions: 1. A line measured in summer with a 100 foot tape, 70° F. temperature, 12 pound pull is found to be 438.945 feet long; measured again in winter at a temperature of 10° F., with the same tape and same pull, what should be its length (tape supported in both cases on level supports)? p. 40, § 62. 2. A tape is 100 feet long, $\frac{1}{4}$ inch wide, $\frac{1}{200}$ inch thick and weighs

.0005 pounds per inch; standard at 62° F., 12 pound pull. A line measured when the temperature is 90° F. and the pull 20 pounds with the tape supported at the two ends only is found to be 93.41 feet long. Required the corrected length of the line. 3. Compare the pull required to balance the sag as obtained in the third experiment above with that obtained theoretically from the formula at the bottom of page 41, using the tape described in the preceding question.

Exercise C-6.

Measuring a Base Line.

References: Page 57, § 82.

Equipment: Steel tape, scale, spring balance, thermometer, magnifying glass (if desired a turn-buckle device for stretching the tape).

Directions: 1. On a level stretch of ground set stakes with their tops on a level, making a line several hundred feet long. Measure the length of this base line a number of times as directed on page 57. 2. Find the probable error as explained on page 58 (read also pp. 15–19).

Suggestions: As it will require considerable time to set stakes, this may be done once for all and the same stakes used by different squads.

Questions: 1. What should be the maximum discrepancy between two measurements of a line 1000 feet long, that the work may be classed as excellent? pp. 48, 49. 2. Is a large error more likely to occur from a variation in temperature or a variation in pull? p. 43. 3. Give the relative importance of different sources of error. p. 43. 4. State some of the requirements corresponding to a ratio of precision of 1/50000. p. 51. 5. When it is impracticable to set stakes with their tops on a level, how would you proceed? p. 57. 6. How can tripods be employed in chaining a base line through thick underbrush? p. 58. 7. Sketch a device for supporting and stretching a tape. 8. Give ideal conditions for base line measurement. 9. What is the object in having the end of the tape fall on a different stake each time a line is chained? 10. Describe other apparatus for measuring base lines. p. 194. 11. Give some practical suggestions for setting supporting stakes, protecting end hubs, etc. p. 57.

Exercise C-7.

A Chain Survey of an Irregular Polygon.

Reference: Page 56, § 80.

Equipment: Chain or tape, chain pins, range poles, plumb bob.

Directions: 1. Set 5 stakes at random, forming an irregular polygon each side of which is at least 150 feet long. 2. Survey this polygon with a tape as explained on page 56. 3. Compute the area of the polygon by finding the area of each of the triangles into which it is subdivided from formula 12 on page 408.

Suggestions: A survey of some plot of land having straight boundary lines may be substituted if desired. For a survey of a plot with irregular boundary lines see page 15 of this book.

Field Notes: 1. A sketch showing all measurements. 2. The computations for areas neatly arranged.

Questions: 1. How can the angles of the polygon be found from the original measurements? 2. Give the general method for making any chain survey. p. 56. 3. If in the survey shown in Fig. 80, p. 56, it were impossible to see all four corners from any one station, how would you proceed?

Exercise C-8.

To Chain from a Given Point over the Brow of a Hill to Another Point.

Reference: Page 55, § 79.

Equipment: Tape, chain pins, sight poles, plumb bobs.

Directions: Set two poles, one over the brow of a hill from the other, and chain the distance between them, as explained on page 55.

Questions: 1. Give two methods of "ranging in" when a valley intervenes between the two points. p. 56, § 79 (c). 2. Give the method of chaining over a high wall. p. 54. 3. Give a method of chaining a line between two points when woods intervene. p.54.

Exercise C-9.

Laying Out a Right Angle with a Tape by the 3-4-5 Method.

Reference: Page 60.

Equipment: Tape and chain pins.

Directions: 1. Set two pins in the ground 80 feet apart and with this line as one side, stake out an 80 foot square. 2. Check by measuring the two diagonals of the square.

Field Notes: Make a sketch showing each distance measured or laid off and the discrepancy between the two diagonals.

Questions: 1. Explain the difference between the methods of laying out a right angle with a cloth tape and with a steel tape (a 100 foot tape being used in each case). 2. How would you lay off a right angle with a 50 foot tape? 3. If one diagonal of a square as staked out is longer than the other how would you proceed to correct the mistake? 4. If the two diagonals are exactly equal, does this necessarily prove that the square has been staked out correctly? 5. How closely should the lengths of the two diagonals of an 80 foot square agree to indicate good work? 6. How would you proceed to stake out the house on page 210, using only the tape?

Exercise C-10.

To Erect a Perpendicular with a Tape at Any Point in a Line.

Reference: Pages 61, 62 and 63.

Equipment: Tape and chain pins.

Directions: 1. Set two pins at random and at one of them erect a perpendicular to the line between them by the method of § 85 (b), p. 61. 2. Check by the 3-4-5 method.

Field Notes: Make a sketch showing all measurements.

Questions: 1. What is the difference between the methods used for geometrical constructions in drafting and those used for the same constructions in chaining? Illustrate by sketches. 2. What method in chaining corresponds to erecting a perpendicular by intersecting arcs and how may the perpendicular erected by this method be checked by the use of the same method? p. 61. 3. Illustrate, by sketches, methods of dropping a perpendicular to a given line from any given point. p. 62.

Exercise C-11.

To Run One Line Parallel to Another Line.

Reference: Page 62 and page 63.

Equipment: Tape and chain pins.

Directions: Assume three points at random and through one of them establish a line parallel to the line between the other two, using two different methods.

Field Notes: Make a sketch showing all measurements.

Question: Discuss the advantages and disadvantages of the three methods given on page 63.

Exercise C-12.

To Measure between Two Points when a Corner of a Building Intervenes.

Reference: Page 64, § 87 (a).

Directions: 1. Assume two points at least 40 to 60 feet apart and imagine a corner of a building to intervene. Find the distance between the two points by one of the methods explained on page 64 and check the result by the other method. 2. Check also by a direct measurement.

Suggestion: Having completed the exercise with an imaginary obstacle, it is well to repeat the work with the corner of a real building intervening between the two given points.

Field Notes: Make a sketch showing all measurements made during the exercise, and the final results.

Exercise C-13.

To Measure to an Inaccessible Point.

Reference: Page 64, § 87 (b).

Equipment: Chain and chain pins.

Directions: 1. Set two stakes or pins about 200 feet apart. 2. Find the distance between the two points by two different methods. 3. Check results by direct measurement.

Questions: 1. Could the methods used in transit work (p. 222, § 277 (c)) be used in chaining? 2. Explain at least two other methods that might be used with a tape. § 87 (c). 3. Describe a rough method of measuring the height of an inaccessible point. § 87 (d). 4. Describe at least two methods of prolonging a straight line through an obstacle using only the tape. p. 66. (If time permits this may be done in the field as an additional exercise.) 5. Show by a sketch one method of measuring between two inaccessible points. § 87 (e).

Field Notes: 1. A sketch showing all measurements. 2. Arithmetical work neatly arranged.

Exercise C-14.

To Measure the Angles of a Triangle with a Tape.

References: Page 63, § 86, and pages 458–460.

Equipment: Tape and chain pins.

Directions: Set three stakes or chain pins at random to form a triangle with no side less than 100 feet long. 2. Measure each interior angle of the triangle with the tape using the tangent method. 3. Repeat the problem using the chord method.

Suggestions: 1. Take a reasonably long distance for the base in the tangent method and the radii in the chord method. 2. Pay particular attention to lining in — the errors are chiefly here.

Field Notes: 1. A sketch of the triangle showing all measurements for the first method; a similar sketch for the second method. 2. All arithmetical work neatly arranged. 3. A comparison of results of the first and second methods. 4. Actual error in the sum of the angles.

Questions: 1. Illustrate how to measure angles of various sizes from 0° to 360° by the tangent method; by the chord method. 2. What is the most convenient base or radius? 3. Upon what does the accuracy of the tangent method depend? 4. When is it advantageous to use the chord method instead of the tangent method? 5. Explain the sine and cosine method. p. 63.

Exercise C-15.

A Chain Survey of a Plot of Ground with Irregular Boundary Lines and Containing Buildings.

References: Page 56, § 80, also pp. 138 to 140.

Equipment: Steel tape, chain pins, stakes, hatchet and range poles.

Directions: Make a survey of a small plot of ground in which some of the boundary lines are curved or irregular. There should also be some buildings to be located. Establish a network of triangles for reference lines as explained on page 56, § 80 (c), and locate the different details as explained on pages 138–140.

Suggestions: If desired this exercise may be conducted as a recitation, the different methods being discussed by the class as a whole, or by each squad, and each method illustrated by sketches on the blackboard or in the note-book.

Field Notes: 1. A complete sketch showing all measurements made in the field. 2. Computations for area neatly arranged.

Questions: 1. Give the methods of locating a point from two given points by linear measurement only. p. 4. 2. Explain method of locating a building by means of offsets. p. 138, § 198 (a). 3. Explain the method of locating a regular curve by offsets. § 198 (b). 4. Explain the method of locating an irregular outline like the bank of a stream, by linear measurements only. 5. What three points must be kept in mind in using the offset method? § 198 (d). 6. Explain the "plus system" often used in the offset method. *Note,* p. 139. 7. Explain how to locate a building by three measurements, one of which is a tie line. Figure 199 (a). 8. Is it necessary that the tie line should have one end at some point on the building? p. 140. 9. Explain how to locate a building by two pairs of intersecting measurements. Figure 199 (b). 10. Explain the use of tie lines in getting the directions of fences. § 199 (c). 11. How may the area of the plot surveyed be computed? pp. 410–413. (If time permits, compute the area of the plot surveyed.)

Exercise C-16.

Discussion of the Errors in Linear Measurements.

References: Chapter V, pages 39 to 53.

Questions: 1. What are the four general sources of error in chaining? p. 39. 2. How is an error expressed by a ratio? 3. If a line is measured with a tape that is too short, will the result be too short or too long, and what is the corresponding algebraic sign? 4. Why is the error in the length of a chain likely to be relatively greater than that in a tape? 5. Show by an illustration how to apply a correction for an error in the length of a tape when chaining between two points; when laying off a given distance. p. 40. 6. How can an error due to the tape not being horizontal be eliminated? 7. When is the error due to temperature plus, and when minus? 8. What is the approximate change in the length of a 100-foot steel tape for a change in temperature of 90° F.? 9. When should temperature be taken into account and when not? 10. What precautions are often taken in base line measurement to eliminate the error due to temperature? 11. What approximate rate of change may be remembered for a 100-foot tape? 12. If the length of a city block is measured in summer and then again in winter with the same tape, what discrepancy due to change in temperature may be expected? 13. Describe an experiment which may be tried to show the effect of a small change in temperature upon the length of a steel tape. 14. What is meant by the error in alignment, and is this source of error relatively important? p. 41. 15. In ordinary chaining, is it necessary for the transitman to line the chainman in with the instrument? 16. Is an error due to sag plus or minus? 17. What three ways are there of eliminating the error due to sag? 18. How may the error due to uneven pull be eliminated? p. 42. 19. How may the errors in marking tape lengths be reduced? 20. In what kind of work is this source of error the greatest? 21. Name four common mistakes made in reading tapes. 22. In extremely accurate work, what precautions may be taken in reading the tape? 23. Summarize the eleven sources of errors in chaining. p. 43. 24. From what two sources are errors compensating? 25. What errors are always plus? 26. Discuss the relative importance of the sources of errors, pointing out from which sources imporant errors are most likely to occur, and what sources may be neglected in ordinary work. 27. In judging the relative importance of errors, what points should be kept in mind? p. 44. 28. What largely determines limits of error in a given survey? 29. Should all measurements in the same survey be made with equal care? 30. In general, what distances should be measured carefully and what less carefully? p. 45. 31. What are some of the conditions that affect the accuracy of chaining? 32. If the accidental errors amount to 0.02 foot for 100 feet in using a 100-foot tape, what would be the probable error in measuring a line 900 feet long? 33. Give the general rule for finding the probable error. 34. Why is not the discrepancy between two measurements of the same line affected by constant errors? 35. If the discrepancy between two measurements of the length of a tape is 0.01, what is it likely to be between two measurements of a line sixteen tape lengths long? 36. What can you say regarding the value of the formula at the top of page 46? 37. Discuss the remark at the top of page 46, and explain why the last sentence in that remark is true. 38. Explain the first method of determining a coefficient of precision for chaining. 39. Explain a method which may be used for ordinary chaining. 40. A line is chained twice under favorable conditions, measurements being made with an ordinary chain, plumb-bob, chain-pins and average speed. The two results were, respectively, 618.1, 618.3. Would the work be classed excellent, good, or fairly good? (See Table 1, p. 48.) 41. If a steel tape had been used in place of a chain, other conditions being the same, what would be the allowable discrepancy in good work between the two measurements in the preceding question? 42. Apply Table 2, page 49, to questions 40 and 41. 43. Explain how the table on page 51 may be used to indicate the precautions which are necessary to attain certain degrees of precision. p. 52. 44. Discuss the matter of combining errors from different sources. p. 52.

GROUP T.

EXERCISES IN THE USE OF THE TRANSIT.

The exercises in this group offer the student an opportunity to form correct habits in manipulating the transit and in reading angles. As habits formed early in the course are likely to cling to one long after graduation, and as the transit is perhaps the most important instrument used in surveying, no suggestion, however trivial it may seem, should be ignored if it is likely to help one to become skilful and accurate in the use of the transit.

Exercise T-1.

Setting up a Transit.

References: Pages 84–89, §§ 109–115.

Equipment: A transit for each student, or as many transits as are available.

Directions: 1. Set up the transit on comparatively level ground, paying special attention to the suggestions on page 87. 2. Repeat the work, selecting a place on a side hill.

Suggestions: At the beginning of the exercise, it is well for each instructor to show his squad how to set up a transit, emphasizing at the same time the importance of the suggestions on page 87, § 114. The members of the squad may then be drilled individually under close supervision of the instructor, several transits being used simultaneously, if possible.

If this exercise is given before the exercises in the use of the level, it is well for the instructor to explain briefly the principal parts of the telescope (see photograph, page 551), and, if thought best, to add to the questions given below those on pages 96 and 97 of this book.

Questions: 1. Give some of the precautions to be observed (a) in the use of clamps and screws; (b) in the treatment of lenses; (c) in standing a transit up on a floor. p. 84. 2. Give precautions taken in carrying a transit. p. 85. 3. Give other precautions. pp. 607–609. 4. Tie a sliding knot as described on p. 85. (If the knot slides too freely, take an extra turn of the string about the hook.) 5. How are the cross-hairs brought in focus? p. 85. 6. Give the rule for focusing the object glass on distant objects. p. 86. (If desired, the theory of lenses (pp. 545–549) and the construction of the telescope (pp. 549–558) may be studied in connection with Questions 5 and 6.) 7. Give suggestions for sighting the telescope. p. 85, § 111. 8. Give some practical suggestions for manipulating the tripod. p. 86, §§ 113, 114. 9. Give suggestions for leveling up. p. 88. 10. Explain how the telescope level is sometimes used for leveling up. p. 89. 11. If the plumb-bob is as much as $\frac{1}{4}$ to $\frac{1}{2}$ of an inch off the tack, how much will this affect an angle if sights are 450 feet long? p. 89 and p. 105, § 147. 12. Give some points to remember in leveling up. p. 89, § 115.

Exercise T–2.

Prolonging a Straight Line.

Reference: Pages 90–93, §§ 116–122.

Equipment: Transit, hatchet, and stakes.

Directions: 1. Set two stakes at random, at least 200 feet apart, in such a place that the line between them can be prolonged another 200 feet. 2. Set up over the end of the line to be prolonged, and set a third stake in line about 200 feet away, using the method of double reverse. p. 92. 3. Set up over the other end of the original line and see if all three stakes are in line.

Suggestion: Drive the stakes only part way into the ground so that they may be pulled up easily. Mark the exact points with a small lead-pencil cross.

The *upper* clamp should be set once for all at the beginning of the exercise, and left undisturbed during the remainder of the exercise. The student should then work wholly with the *lower* clamp and corresponding slow motion screw, and thus become accustomed to using them for *backsighting.* Not until *Exercise T*–4 should he concern himself with the use of the *upper* clamp and the corresponding slow motion screw.

It may be well, at the close of the exercise, for the instructor to explain briefly by means of the figures on pages 588 and 590 what errors of adjustment may be eliminated by reversing in azimuth and altitude.

Field Notes: A short statement of the work and of the discrepancy, if any, found in the final check of the third step above.

Questions: Define backsight, foresight, permanent backsight, and permanent foresight. p. 90. 2. Explain the use of the upper and lower clamps and the corresponding tangent screws. p. 91, § 119, pp. 563–566. 3. Give signals for lining in. p. 146. 4. Explain the method of reversing in azimuth and altitude; what are other synonymous terms? p. 92. 5. In setting up to prolong a straight line, what precaution may be taken? p. 89 (14); also note, p. 92. 6. What four methods are there for prolonging a straight line?

Exercise T-3.

Balancing in a Transit.

References: Page 93 and page 201.

Equipment: Transit, hatchet, stakes, and sight poles.

Directions: Set two stakes several hundred feet apart, and balance in the transit about half way between them as explained on page 201. 2. When the transit is apparently on line, test by the method of double reverse.

Exercise T-4.

Reading the Limb of a Transit.

References: Pages 67–75.

Equipment: A transit for each student, or as many transits as are available.

Directions: 1. Clamp the plates of a transit at random, read the number of degrees (clockwise), estimate the number of minutes, and record the total reading. *Pay no attention to the vernier reading.* 2. Record the correct reading as given by the instructor (who will read the vernier). 3. If the transit has two verniers 180 degrees apart, repeat for the reading across the circle. 4. Repeat the whole exercise until from 6 to 10 different readings have been made and recorded by each student.

Suggestions: If a number of transits are available for each squad, they may be set up within a few feet of each other, and the plates of each transit set at random by the instructor. Each student may then read in turn the limb of each transit. *No vernier readings should be permitted*, as the object of the exercise is to make each student thoroughly familiar with the method of reading the limb before he undertakes to read the vernier. After the student has become accustomed to reading the angles clockwise, he may be drilled in reading the angles counter-clockwise.

At the beginning of the exercise it is well for the instructor to explain briefly how the upper and lower plates may be turned independently or together, and to illustrate the use of the upper and the lower clamps and the corresponding slow motion screws. The photograph on page 565 should be useful in this connection.

If transits with special forms of numbering are available, as, for example, one like that described in Article 95 (d), page 73, a special drill should be given in reading such instruments.

FORM OF NOTES.

Number of Reading.	Value.	Instructor's Reading.
1	37° 15′	37° 18′
2	108° 40′	108° 38′

Questions: 1. Which plate, the limb or that carrying the vernier, must necessarily turn when the telescope is moved sidewise? pp. 67, 563. 2. Give the three common systems of numbering the limb gradations. p. 67. 3. Give four common methods of subdividing the degree on the limb. p. 68. 4. Give the three steps in reading an angle. p. 68. 5. In which step are important mistakes liable to occur? Remark, p. 68. 6. Explain what is meant by reading an angle clockwise and counter-clockwise right and left (p. 68), and why are the first two terms preferable to the last two terms? Remark, p. 69. 7. Give general method of reading a limb. § 91 (b), p. 68. 8. Give common mistakes in reading a limb. p. 69. 9. If angles are always measured clockwise, what system of numbering is best for the transit (p. 71) and how many rows of numbers would be needed? p. 67. 10. In measuring angles clockwise, which row of numbers on page 70 is ignored? 11. Why is the portion of the limb near the 180-degree mark a place where mistakes are liable to occur? p. 71, § 94 (b). 12. Why is it important to check readings by estimating angles with the eye? p. 71, § 94 (b). 13. What mistake is illustrated by most of the incorrect readings on page 70? p. 71, § 94 (c). 14. What mistake is illustrated by the reading of 171° 30′ in place of 191° 30′? p. 70, § 94 (c). 15. If a transit has only one row of numbers (clockwise), and it is desired to read an angle counter-clockwise, how would you proceed? § 94 (d), p. 71. 16. If a transit has only one row of numbers, and that is the half-circle system, how would you read an angle clockwise which is greater than 180°? p. 73, § 95 (c) and (d). 17. When gradations are numbered by a combination of the full-circle and quadrant systems, what is a common mistake? p. 75, § 96 (b), and at what two points on the limb are mistakes most likely to occur? (Bottom of p. 75.)

Note: As a result of this exercise two things should be impressed upon the mind of the student, first the importance of reading the *limb* correctly before attempting to read the vernier, and, second, the closeness with which an angle may be read *without* the use of a vernier.

Exercise T-5.

Reading Angles; Limb and Vernier.

References: Pages 76–83.

Equipment: A transit for each student, or as many transits as are available; preferably transits should read to minutes.

Directions: 1. Clamp the plates of a transit at random, and read both the limb and vernier clockwise, recording the total reading. 2. Record the correct reading as given by the instructor. 3. Repeat for the vernier across the circle. 4. Repeat the whole exercise until from six to ten readings have been made and recorded by each student.

Suggestions: Several transits may be used by each squad as in the preceding exercise. It is well, however, to confine the work to transits reading to minutes until the method is thoroughly understood, then transits reading 30, 20, or 10 seconds may be used. Finally, students should be drilled in reading angles counter-clockwise.

Form of Notes.

Same as that for the preceding exercise.

Questions: 1. What is the principle of the vernier? pp. 538, 539. 2. What is the difference between direct and retrograde verniers? p. 540. 3. Explain how to determine the smallest reading or least count of a vernier. p. 540; also p. 76, § 97 (c). 4. In the vernier reading to minutes, how large an arc is covered by the space that is called a minute? p. 76, § 97. 5. Give the general method of reading a vernier. § 98. 6. Which side of a double vernier should be read? § 99. 7. Why should the vernier reading be estimated from the limb before the vernier is read? § 99 (2). 8. How many marks should be examined closely in reading the vernier? § 99 (3). 9. When may an angle be read to 30 seconds on a vernier reading to minutes, and what is the greatest error involved in reading such a vernier? § 99 (3). 10. What precaution should be used in setting a vernier? § 99 (4). 11. When there are two verniers 180° apart, which is ordinarily used? § 99. 12. What are some of the common mistakes in reading verniers? p. 77. 13. Describe at least three different verniers, each of which reads to minutes? pp. 78, 79. 14. Describe a common form of vernier reading to 30 seconds. p. 80. 15. Describe a common form of vernier reading to 20 seconds. p. 81. 16. Describe a common form of vernier reading to 10 seconds. p. 82. 17. Describe some special forms of verniers. p. 83.

Note: **Different forms of verniers may be assigned to students to be drawn on paper outside of the regular exercise.**

Exercise T-6.

Measuring Horizontal Angles with a Transit.

References: Pages 93–98, §§ 125–133.

Equipment: Transit, stakes, hatchet, and sight poles.

Directions: 1. Set four stakes $A, B, D,$ and $E,$ at random to form an irregular polygon, no side of which is less than 150 feet in length. 2. Set a stake C near the center of this polygon. 3. Set up the transit over C, and measure in succession the horizontal angles $ACB, BCD, DCE,$ and ECA, all measured clockwise. Make a sketch showing the values of the angles. 4. Check by comparing the sum of the four angles with 360°.

Questions: 1. Give the general method of measuring horizontal angles. p. 93. 2. Which clamp and tangent screw is used for each operation? Bottom of p. 93, top of p. 94. 3. Explain the difference between taking the angles to the right and to the left. p. 94. 4. Explain how a number of angles may be taken from the same backsight. p. 94. 5. Is the vernier always set at 0 before measuring an angle? p. 94. 6. If there are two verniers, which is used? p. 95. 7. Why form the habit of estimating the angles by eye? p. 95. 8. Precautions to take after backsighting. p. 95. 9. Precautions to take in measuring a large number of angles from the same backsight. p. 95, § 129 (6), (7), (8). 10. In taking angles clockwise, is it necessary to turn the telescope clockwise? 11. Name some of the sources of error in measuring the horizontal angles. p. 96. 12. Give some suggestions for using the vernier in reading the angles. p. 96. 13. Name some common mistakes in reading angles. p. 97. 14. Relative importance of errors. p. 104. 15. Relative importance of error in setting up the transit. p. 104. 16. If a pole is ¾ inch in diameter and is held 100 feet from the transit, what would be the angular error caused by bringing the vertical cross-hair to coincide with the edge of the pole instead of with its center? Bottom p. 105. 17. Is the difference between the sum of the four angles and 360° the *true* error of that sum or simply a *discrepancy?* p. 14, § 24 (b). 18. How would you distribute this error? p. 14, § 24 (c). 19. If two angles *ACB* and *BCD* were measured separately, and then checked by measuring *ACD*, would the difference between the sum of the first two angles and the measured value of *ACD* be a true error, or simply a discrepancy, and how would it be distributed? § 24 (d). 20. What method corresponding to the work done in this exercise is sometimes used in work of high precision? p. 100, § 139.

Exercise T–7.

Practice in Doubling Horizontal Angles.

Reference: Page 99, § 138.

Equipment: Same as for the preceding exercise.

Directions: Repeat the preceding exercise, but double each angle as explained in § 138.

Questions: 1. Explain the method of measuring angles by repetition. p. 99. 2. What is the chief precaution necessary in manipulating clamps and tangent screws when repeating an angle? p. 100. 3. When is it necessary to add multiples of 360°? Illustrate how this is done. 4. Explain how to lay off an angle accurately. p. 101, § 142; also p. 218.

Exercise T–8.

Measuring Vertical Angles with a Transit.

Reference: Page 98, § 135.

Equipment: Transit, stakes, and hatchet.

Directions: 1. Drive two stakes *A* and *B* about 200 feet apart, *B* being considerably lower than *A*. Set up over *A* and measure the vertical angle which the line of sight from the transit to *B* makes with the horizontal. 2. Assume some well-defined point at least 50 feet above the ground and 200 feet from the transit; call this point *C*, and measure the angle which the line of sight from the transit to *C* makes with the horizontal. 3. Measure the vertical angle between the lines of sight to *B* and to *C*. Make a sketch showing the values of all angles. 4. Check by comparing the last angle measured with the sum of the other two angles.

Questions: 1. How should the vertical arc be adjusted, assuming that the transit is in adjustment otherwise? p. 98, § 135. 2. How would you proceed if neither the vertical arc nor the corresponding vernier were adjustable? 3. What is the "index error," and how are the algebraic signs applied to it? p. 98. 4. In measuring the vertical angles as directed above, where is the vertex of the angle? 5. If it were required to measure a vertical angle, one side of which was determined by two points on the ground, how would you proceed, assuming that all points are accessible? 6. Is it possible to double a vertical angle with a transit as ordinarily made? 7. How can a transit be made so that it will be possible to double vertical angles?

Exercise T–9.

To Find the Intersection of Two Lines of Sight.

Reference: Page 202.

Equipment: Transit, stakes, hatchet, wire brads, short pieces of string.

Directions: 1. Set four stakes at random to form a polygon, no side of which is less than 150 feet in length. 2. Find the intersection of the diagonals of this quadrilateral as explained in § 257.

Questions: 1. Explain the method of referencing a point. § 259. 2. Give other methods of referencing a point. p. 54. 3. How would you reference a point for setting a merestone? p. 203, § 259. *Illustration.* 4. Give two methods of referencing a line. § 260. 5. Explain the importance of referencing at least one line in a survey. § 260. *Remark.*

Exercise T–10.

To Establish a Line of Sight Parallel to a Fence or to a Building.

Reference: Page 201, § 256.

Equipment: Transit, tape, stakes, hatchet, sight pole.

Directions: 1. Assume a station about three feet from a fence or a building. 2. Set the transit over the station and establish a line of sight parallel to the fence or to the building as directed on page 201.

Field Notes: Make a sketch showing the fence or building, the transit line and the distance used. Describe the method referring to the sketch in order to make it plain.

Questions: 1. What method would you use when the parallel lines are a considerable distance apart? p. 224, § 278 (b).

Exercise T–11.

To Measure the Angle Formed by Two Intersecting Lines without Setting Up over Either Line.

Reference: Page 202, § 258.

Equipment: Transit, tape, hatchet, stakes, sight pole, pieces of string.

Directions: Measure the angle at any place where two definite fence lines meet, choosing preferably a corner where the transit cannot be set up inside of the fence line, using the method of § 258.

Suggestion: If it is inconvenient to use actual fence lines, drive three stakes to form a triangle no side of which is less than 200 feet in length, and measure the interior angle at one of the vertices without setting up over any vertex or over any point within the triangle. Three parties may work on the same triangle, one at each vertex, and the sum of the three results may then be compared with 180° as a check.

Questions: 1. What method can be used when the transit can be set up over a point inside of the corner? 2. How are division fences usually set? 3. How are division walls usually set? 4. How are fences along a street usually set? 5. How are street lines usually marked?

Exercise T-12.

Discussion of the Errors in Angular Measurement.

Reference: Chapter X, p. 104.

Questions: 1. What in general are six sources of error in measuring angles? p. 104. 2. What can you say regarding the relative importance of errors from these different sources? 3. If the plumb-bob is slightly off the tack is the resulting error likely to be large? p. 105. 4. When is the error due to the plates being out of level likely to be large? 5. Why is the error due to either source greater for short sights than for long sights in *measuring* angles? Why is the reverse true in *laying off* angles? 6. If the bob is ½ inch off the station, what, approximately, are the resulting errors for sights of 100 and 1000 feet respectively? 7. Give some idea of the errors involved when one edge of the limb is lower than the other. 8. In measuring an angle what values should be kept in mind when judging the importance of errors of sighting? (Note (*b*), p. 106.) 9. What values in laying off angles? 10. Explain by means of these values the importance of holding the sight pole plumb. 11. Suppose that in measuring an angle to the nearest minute the length of sight is 800 feet and only the top of the pole is visible, how much could it be out of plumb without materially affecting the result? 12. What are some of the natural sources of error? 13. Explain how the sun shining on one side of the instrument and not on the other might affect a line of sight. 14. Give some precautions which may be taken to avoid mistakes; to eliminate constant errors; to eliminate accidental errors. 15. In what two ways may the precision of angular measurement be judged? p. 107. 16. Explain each of these two methods. 17. Explain the fundamental difference between checking angles by the *true* error of their sum and by the *discrepancy* between their sum and a *measured* angle. 18. If the sum of the interior angles of a polygon agrees with the check of § 175, p. 119, does this mean that the measured value of each angle is exactly right? 19. If the interior angles of a triangle are measured with a coarsely graduated instrument why is their sum more likely to be exactly 180° than if a finely graduated instrument were used? 20. What are some of the conditions which effect the precision of angular measurement? p. 108. 21. Suppose that the ratio of precision for chaining has been fixed at $\frac{1}{10000}$, what is the permissible error for an angle? (See table at bottom of p. 108.) 22. If an error of 30″ is made in laying off an angle what is the error in feet at a distance of 1500 feet from the transit? 23. What can you say regarding the permissible angular error in ordinary transit surveying? p. 109. 24. For limits $\frac{1}{30000}$ or higher what are the permissible angular errors, and how may this degree of precision be attained? 25. What is meant by consistent accuracy as applied to the relation between linear and angular measurement? 26. When is it not desirable to maintain this consistent accuracy? 27. Suppose that contour points in a survey should be located to the nearest foot and the longest sight does not exceed 600 feet, how accurately must angles be read, and will it be necessary to use the vernier? 28. How accurately must an angle be measured to locate a point 800 feet from the transit within ½ inch? 29. A corner of a building is 60 feet from a transit and an angle and a distance are measured to it solely for purposes of plotting to a scale of 1 inch = 50 feet, how accurately should each be measured? (Use 500 feet in the table at the bottom of page 108, changing the position of the decimal point.) 30. If the permissible error in a single angle is 20″, what is the permissible error in the sum of the interior angles of a 25-sided polygon? p. 110. 31. What would be the permissible error in the same polygon if the sides averaged 400 feet in length, and the largest discrepancy allowed between two measurements of the same line were 0.1 foot? 32. Is it the general tendency in transit surveying to overestimate the accuracy required in angular measurement and underestimate that required for linear measurements, or *vice versa?*

GROUP TR.

EXERCISES IN RUNNING TRANSIT LINES.

General Directions for Exercises Tr–1 to Tr–11.

The following eleven exercises are intended to fix in mind the methods explained in Chapter XII, p. 116. These exercises are of the greatest importance, since they are preparatory to actual surveys to be taken up later in the course.

In all problems drive three or more stakes at random to form a triangle or polygon, no side of which is less than 150 feet. *Mark each stake so that different parties will not use each other's stations by mistake.* It is not necessary to drive stakes flush with the ground; indeed, it is better to drive them only partway in. In the top of each stake drive a wire brad, leaving enough of the nail projecting above the stake to serve as a sight, thus avoiding the necessity wherever possible of holding a pencil or a pole on the stake.

In the direct angle methods measure all angles to the right, unless otherwise stated. Unless it is desirable to gain additional practice in chaining, measurements of the lengths of the sides of triangles or polygons may be omitted. In most of the exercises two men can work to advantage in a party. Each should check the other's work, keep complete notes, and divide the work of running the transit. Thus, for example, if the party consists of two men, one can run the transit at one station, the other at the next station, and so on, alternating. In the azimuth method, however, it is desirable for one man to run the transit entirely around the triangle or polygon, and then the exercise should be repeated, the other man running the transit. It is well to choose a comparatively level piece of ground for all of these exercises, where no difficulty will be encountered in sighting.

Equipment for Exercises Tr–1 *to Tr*–11: A transit reading preferably to minutes, and for all exercises except deflection angle exercises, graduated according to the full circle system. Also hatchet, stakes, wire brads, crayon, and in some cases sight poles. If the lengths of sides are to be measured, a tape and plumb-bob should be added to the equipment.

Exercise Tr-1.

Survey of a Triangle or Polygon by the Direct Angle Method.

References: Pages 116–120, §§ 162–178.

Equipment: See page 29 of this book.

Directions: 1. See general directions, page 29 of this book. 2. Survey the triangle or polygon without doubling angles, measuring the interior angles. Keep notes according to Form 1, p. 170. Follow as far as possible the method of procedure on p. 154, § 220 (a).

Questions: 1. Define transit station, transit line, and transit angle. p. 116. 2. What are transit lines used for? p. 116, § 165. 3. Give the general method of running transit lines. p. 116, § 166. 4. Define transit-line angle and explain how to avoid ambiguity in the notes. p. 117, § 167. 5. Define deflection angle, a system of transit lines, traverse, triangulation. 6. What is the difference between angles to the right and angles to the left? p. 118. 7. If angles are measured to the right, in what direction must one go around a polygon in order to measure interior angles? p. 118, § 173. 8. Give the rule for a closing check on transit-line angles. 9. If the ratio of precision in chaining for a given survey is $\frac{1}{5000}$, how accurately should transit-line angles be measured to obtain a corresponding degree of accuracy in angular measurement? p. 108, § 152. 10. If the permissible error in the measurement of a single angle is 30 seconds, what is the permissible error in the sum of the interior angles of a polygon of nine sides? p. 110. Is this error the same thing as "error of closure"? p. 119.

Questions on Methods of Keeping Field Notes in Transit Surveying: 1. Describe the different systems of keeping field notes. p. 164, §§ 229 and 231. 2. How may notes pertaining to transit lines be distinguished from other notes, and what is the object in doing this? p. 165, § 230. 3. Explain the tabulated form of notes. § 232. 4. Explain the sketch method. § 233. 5. Explain the combination method. § 234. 6. Compare the three methods. 7. When should notes read from the bottom up? § 235. 8. What should the field notes include? § 236. 9. Give suggestions for avoiding crowded notes. § 237. 10. Give general suggestions for keeping field notes. §§ 239 and 240. 11. Give the advantages and disadvantages of Form 1, p. 170.

Exercise Tr–2.

Measuring the Exterior Angles of a Triangle or Polygon.

References, Equipment, and Directions, same as for the preceding exercise, except that exterior angles are measured instead of interior, by going around the polygon in the opposite direction.

Exercise Tr–3.

Doubling the Interior Angles of a Triangle or Polygon.

Reference: Page 99, § 138.

Equipment: See page 29 of this book.

Directions: 1. See general directions, page 29 of this book. 2. Measure the interior angle of the triangle or polygon, doubling each angle according to the method on p. 99, § 138. Keep notes according to Form 4, p. 173, omitting the last two columns. Follow as far as possible the method of procedure on p. 154, § 220 (b).

Questions: 1. Explain the method of measuring angles by repetition. p. 99. 2. Explain the use of clamps in repeating the angles. *Caution,* p. 100. 3. When is it necessary to add multiples of 360°? § 138 (d). 4. What is the advantage of doubling angles? 5. What is the greatest number of repetitions usually used for a single angle? § 138 (c).

Exercise Tr–4.

Doubling the Exterior Angles of a Triangle or Polygon.

References, Equipment, and Directions, same as for the preceding exercise, except that the exterior angles are measured instead of the interior.

Exercise Tr–5.

Measuring the Interior Angles of a Triangle or Polygon, and Checking by Calculated Bearings.

References: Page 126, § 189; p. 101, § 143; pp. 111–113, §§ 153–159; also pp. 541–543, 566; Chapter XXX, p. 378.

Equipment: See page 29 of this book.

Directions: 1. See general directions, page 29 of this book. 2. Set up at any station, backsight on a preceding station, lower the needle on its pivot, and read the bearing of the line to the backsight. p. 101. 3. Measure the interior angle clockwise and check this angle by the calculated bearing as in Chapter XXX, p. 378. 4. Set up at the next station, measure the interior angle, and from the *calculated* bearing of the preceding line calculate the bearing of the next line. Check this calculated bearing by reading the needle. 5. Continue in the same way until the interior angle at each station has been measured. The discrepancy between the bearing of the first line as calculated at the *last* station and the magnetic bearing of this same line as read at the *first* station should equal the error in the sum of the interior angles as revealed by the check on p. 119.

Field Notes: Keep notes according to Form 4, p. 173, omitting of course the double value of the angle. Arrange computations of calculated bearings in a form similar to that on p. 382.

Suggestion: Before beginning this exercise in the field, the class should be drilled in calculating bearings; some of the examples on p. 116 of this book may be given for practice.

Questions: 1. Define magnetic declination, agonic line, local attraction. p. 111, § 153. 2. Define the bearing of a line and illustrate by a sketch. p. 111. 3. Difference between true bearing and magnetic bearing? 4. Why will the true bearing of a line change if the line is prolonged far enough with a transit? 5. Explain what is meant by forward bearing and back bearing and illustrate by a sketch. p. 112. 6. If the bearing of line *AB* is N. 47° W., what is the bearing of *BA*? *Note*, p. 113. 7. Which bearings are usually kept in a survey forward or back? p. 113. 8. Give some of the facts to remember concerning bearings. p. 113. 9. Which end of the compass needle is read? p. 101,

§ 143. 10. When is the other end read? p. 102. 11. Why are positions of the letters E. and W. interchanged in the compass box? p. 102. 12. Give the directions to be observed in reading bearings. p. 103. 13. Explain why the calculated bearings are entirely independent of magnetic bearings. p. 126, § 189. 14. Can the angle at any station be checked by calculated bearings when there is local attraction at that station? *Remark,* p. 126. 15. Suppose that when an angle is measured at the second station, the calculated bearing and the magnetic bearing of the line to the third station do not agree, and that this discrepancy continues at succeeding stations, what would this indicate? 16. Is a true north and south line ever used as a basis for calculated bearings? *Note,* p. 127, p. 124, § 185. 17. What is the check for a closed polygon? p. 127.

Note: For additional questions pertaining to the compass, see Exercise Co-2, page 70 of this book, and for questions pertaining to the calculation of bearings, see page 116 of this book.

Exercise Tr-6.

Measuring the Interior Angles of a Triangle or Polygon to the Left.

References and Equipment, same as for the preceding exercise.

Directions: Repeat the preceding exercise, measuring angles to the left instead of to the right. Keep notes same as for corresponding exercise, except it should be noted that all angles are measured to the left from the backsight. Keep magnetic and calculated bearings.

Exercise Tr-7.

Measuring the Exterior Angles of a Triangle or Polygon to the Left.

Same as the preceding exercise, except exterior angles are measured instead of interior.

Exercise Tr-8.

Measuring the Deflection Angles of a Triangle or Polygon.

References: Page 117, § 168; page 120, § 179; page 155, § 221.

Equipment: See page 29 of this book.

Directions: 1. See general directions, page 29 of this book. 2. Measure the deflection angles of the triangle or polygon according to the method explained on page 120. Keep notes according to Form 5, page 173, following as far as possible the method of procedure on page 155. Assuming the magnetic bearing of the first backsight as a basis, keep the calculated bearings as in the preceding exercises.

Suggestion: If preferred, stakes may be set at random so that the line progresses more or less in one general direction instead of forming a polygon.

Questions: 1. What system of numbering for the graduations on the limb is preferable for measuring deflection angles? p. 75, § 96 (c); also *Remark,* bottom of p. 73. 2. Give a valuable check used in the deflection angle method. p. 155, § 221 (b). 3. If it were desired to double deflection angles, how would you proceed? p. 100, § 138 (e). 4. What error is thus eliminated? 5. What check may be used when calculated bearings are kept? Bottom of page 155. 6. Explain how setting the *B* vernier at the original deflection angle gives a double check. Step 8, p. 155. 7. Explain two forms for keeping notes for deflection angles and the advantages and disadvantages of each. pp. 173, 174.

Exercise Tr-9.

Survey of a Triangle or Polygon by the First Azimuth Method.

References: Pages 114, 115; p. 120, § 180 (a), (b), (c); also p. 156, § 222.

Equipment: See page 29 of this book.

Directions: 1. See general directions, page 29 of this book. 2. Survey the triangle or polygon by the first azimuth method,

p. 121, going around the triangle clockwise. Assume a magnetic north and south line for a meridian. Keep notes according to Form 7, p. 174. Check all azimuths by magnetic bearings.

Suggestion: If the party consists of two men, one should run the transit until the exercise is completed, and then the work may be repeated, the other man running the transit and going around the triangle or polygon in the opposite direction.

Questions: 1. Define the azimuth of a line. p. 114. 2. Why do many surveyors measure azimuths from the south as a starting-point instead of the north? 3. What is the chief advantage in measuring azimuths from the north? 4. Is the azimuth always measured from a north and south line as a reference line? § 160(c). 5. Explain the difference between forward azimuth and back azimuth. 6. Compare the method of measuring azimuths with the method of measuring bearings. p. 115, § 161. 7. Give additional facts to remember about azimuths. § 161. 8. By means of a sketch explain the first method of running transit lines by azimuths. p. 121. 9. What precautions should be taken in beginning a survey by azimuths? p. 123, § 182. 10. How may azimuths be checked by the magnetic needle? p. 124, § 184. 11. If at any station the azimuth and bearing of a line disagree, does it necessarily follow that the former is incorrect? p. 123, § 182. 12. What other meridians are used besides the magnetic north and south line? p. 124, §§ 185, 186. 13. If a true north and south line is used as a reference meridian, how should the compass be adjusted? 14. What is the advantage of such a meridian? 15. What is the disadvantage of using a line assumed at random as a reference meridian? § 186. 16. What is meant by orienting the transit? p. 125. 17. In step 5, p. 156, how does setting the vernier at the forward azimuth act as a check? If the line of sight does not exactly strike the foresight, what should be done?

Exercise Tr-10.

Survey of a Triangle or Polygon by the Second Azimuth Method.

References: Page 122, § 180 (d), §§ 181, 183; also p. 156, § 222 (b)

Equipment: See page 29 of this book.

Directions: 1. See general directions, page 29 of this book. 2. Proceed as in the preceding exercise, but use the second azimuth method instead of the first.

Questions: 1. By means of a sketch explain the second azimuth method. p. 122. 2. Compare step by step the two azimuth methods. § 181. 3. Give the advantages and disadvantages of each of the two azimuth methods. § 183.

Note: If time permits, repeat this problem but go around the triangle or polygon counter-clockwise.

Exercise Tr-11.

Survey of a Triangle or Polygon by the Method of Bearings.

References: Page 125, § 188; also p. 156, § 222 (d).

Equipment: See page 29 of this book.

Directions: 1. See general directions, page 29 of this book. 2. Assume either a true north and south line or a magnetic north and south line as a reference meridian, and proceed exactly as directed in Exercise Tr-9, but use the method of bearings as explained on page 125 instead of the method of azimuths.

Questions: 1. Explain by a sketch the method of running transit lines by bearings. 2. Which of two zeroes on the limb should be called the north zero, and why, in most cases, would this zero really be nearer the south end of a telescope pointed north? *Note,* bottom of p. 125. 3. What is a common mistake in this method? Caution, p. 126. 4. What precautions should be taken in starting the survey? Note, p. 126.

Note: As this method of bearings is not commonly used, it may be well to omit the field work in this exercise, simply discussing the above questions class.

Exercise Tr-12.

Questions on the Methods of Running Transit Lines or Traverses.

Reference: Pages 127–131.

Questions: 1. Give the advantages and disadvantages of the direct angle method. p. 127. 2. Give the method of procedure for the direct angle method at any one station, (a) when angles are not doubled; (b) when angles are doubled. p. 154. 3. Give the advantages and disadvantages of the deflection angle method. p. 128. 4. Give the method of procedure for the deflection angle method. p. 155. 5. Give the advantages and disadvantages of the azimuth method. p. 128. 6. Give the method of procedure for the azimuth method. p. 156. 7. Give the advantages and disadvantages of the method of bearings. p. 129. 8. Give the advantages and disadvantages of the method of calculated bearings. p. 129. 9. Give the advantages and disadvantages of the method of measuring angles by repetition. p. 130. 10. For what purposes are transit lines used? p. 130. 11. Does a system of transit lines necessarily close? p. 130. 12. Does it make any difference whether the exterior or interior angles of the polygon are measured? p. 130. 13. What is the check for the sum of the interior angles of a polygon? p. 119. 14. What is meant by the error of closure? To what is it due? p. 119. 15. Name four methods of running transit lines. 16. What is the principal difference between the direct angle and the deflection angle methods? 17. What are the three different kinds of meridians used in the azimuth method? When would you use one and when the other? p. 130. 18. Give two methods of orienting the transit in the azimuth method. p. 131. 19. What does a discrepancy between the azimuth and the magnetic bearing of a line indicate? p. 131. 20. What is the purpose of keeping calculated bearings, and when would you use this method? p. 131. 21. Name some of the places where any method of checking foresight lines by the magnetic needle would be useless. p. 131. 22. When would you use the method of doubling angles? p. 131.

GROUP Ts.

TRANSIT SURVEYS.

The first three exercises in this group are intended for class-room discussion, the object being to help the student to gain a working knowledge of the general methods used in making an ordinary transit survey. He will then be better prepared to undertake the actual surveys suggested in the last exercise of this group.

Exercise Ts-1.

Discussion of the Methods of Locating Details.

(For questions on the methods of locating details by linear measurements only, see page 15 of this book.)

1. Give the general method of locating objects from transit lines. p. 133. 2. Are all parts of the same object always located from one transit station? p. 133. 3. Give a common method of locating objects by angles and distances. p. 134, § 195 (a). 4. Give the corresponding method for azimuths and distances. 5. Give the method of locating a building by prolonging one side until it intersects the transit line. p. 135. 6. Give a method for locating large or irregular curves. p. 135. 7. Give the method of locating a point by an angle and a distance, when the distance is measured from some fixed point other than the transit station. Illustrate by the location of a building. p. 136, § 195 (d). 8. How is the method of the preceding question used for determining the direction of a street line? § 195 (e). 9. Explain the method of locating an irregular line, as, for example, the bank of a stream, by a base line and two intersecting angles. p. 137, § 196. 10. Give some practical suggestions for locating points on the water by the method of the preceding question, i.e. methods of taking angles, of keeping notes and of giving signals. p. 203, § 261. 11. Give the three-point method of locating points on the water. p. 137, § 197. 12. Give four methods of locating boundary lines. p. 141. 13. Give the advantages and disadvantages of the different methods of the preceding question. pp. 141, 142; also § 216. 14. What are the two most common methods of locating details? p. 156, § 223.

Note: The above questions should be supplemented by a careful discussion of the methods used for locating details in the various surveys illustrated on pages 176 to 190. (See *Questions* 22 to 28 of the next exercise.) Study with special care Illustration V, p. 184, as it shows a large variety of methods of locating details.

Exercise Ts-2.

Discussion of the Methods of Keeping Field Notes.

Reference: Chapter XV, page 164.

Questions: 1. What can you say regarding the different methods of keeping field notes? p. 164. 2. Why should notes pertaining to transit lines be distinguished from all other notes? p. 165. 3. Give several methods of accomplishing this result. 4. Explain the three general forms used in keeping notes? 5. When can the tabulated form be used to advantage? 6. What are the advantages and disadvantages of the sketch method? 7. Give suggestions for keeping notes by the combination method. p. 166. 8. When should notes read from the bottom of the page upward? 9. What two kinds of data should field notes include? p. 167. 10. Give suggestions for avoiding crowded notes. 11. How are several pages of notes made continuous? 12. Give suggestions for a general sketch of transit lines. p. 168. 13. What must be made clear in the notes regarding any linear measurement? Regarding any angle? 14. What is the difference between entering an angle in the notes as *ABC* and *CBA?* (See *Note,* p. 90.) 15. What else must be understood to make a notation such as *ABC* perfectly definite? p. 117. 16. What should be a constant thought in keeping notes? *Suggestions,* p. 169. 17. What are the advantages of Form 1, p. 170? Disadvantages? 18. Interpret the notes on p. 172; give the advantage and disadvantages of this form. 19. Interpret Form 4, p. 173. What unnecessary check seems to have been employed, judging from the notes as they stand? (See *Comments,* p. 154.) 20. Interpret Form 5, p. 173; give the advantages and disadvantages of this form; compare it with Form 6, p. 174. 21. Interpret form 7, p. 174. 22. Describe how the survey on page 177 was made, explaining how the notes for each step were recorded. 23. Describe how the survey on page 179 was made, and comment upon the notes. 24. Describe how the survey shown on the insert sheet opposite page 190 was made. Comment upon special features of the notes. p. 181. 25. Describe the survey on p. 183 and comment upon the notes. 26. Interpret the notes of Illustration V on the insert sheet opposite p. 190, explaining carefully how each point was located. 27. Interpret the notes on p. 187. 28. Interpret the notes on p. 189, and explain important steps in the survey.

Exercise Ts–3.

Discussion of Practical Questions of Field Work in Transit Surveying.

1. Describe the signals commonly used in field work. p. 146. 2. Give the general method of making a transit survey. p. 146; p. 132, §§ 192, 193. 3. Give different methods of establishing a transit station. § 207. 4. Give methods of marking guard stakes. 5. Give suggestions for numbering or lettering stations. p. 147. 6. Give suggestions for choosing a place for a transit station. p. 148. 7. Give methods of referencing a station. p. 148, p. 54, p. 203. 8. What is the first consideration governing field work? p. 149, § 214. 9. What relation between field work and office work should be kept in mind? p. 149. 10. Give suggestions for determining where to run transit lines. p. 149. 11. Illustrate the preceding question by different methods of making a boundary survey, compare the different methods, and show how the field work and office work may be affected by the choice of stations. p. 150. 12. What method of running transit lines would you use for city work? what method for country surveying? for stadia and topographic surveying? p. 151. 13. In what kind of work is the deflection angle method used? p. 151. 14. Are different methods ever combined in the same survey? p. 151. 15. Give suggestions for running transit lines with reference to precautions taken and checks used. p. 152. 16. What are some of the precautions and checks involved in any systematic method of procedure? p. 153. 17. Why should some systematic method of procedure be followed? *Remark*, p. 154. 18. Give the method of procedure for the direct angle method when angles are not doubled; when angles are doubled. p. 154. 19. Give the method of procedure for the deflection angle method. p. 155. 20. Give the method of procedure for the azimuth method. p. 155. 21. When several methods of locating a detail may be employed, give some of the considerations which would influence you in the choice of method. p. 156. 22. Give suggestions for selecting points of an object to be located. p. 157. 23. In filling in the details of a survey, should all measurements be taken with equal accuracy? p. 157. 24. Give suggestions for locating street lines. p. 158. 25. In locating buildings, what is

always necessary to complete the work? *Practical suggestions*, p. 158. 26. Should the lengths of boundary lines be measured? 27. If the corner of a building is 100 feet from the transit, and the map is to be plotted to the scale of one inch equals 50 feet, how close should the angle to a corner be read for the purpose of locating the corner by angle and distance? See *Question*, p. 158; also p. 105, § 147. 28. Give some general suggestions for staking out work. p. 158. 29. Discuss the different methods of keeping field notes. pp. 164, 165, 166. 30. Give general suggestions for keeping field notes. pp. 167–169. 31. Summarize the important points brought out in the discussion of errors. p. 159, § 226. 32. What are the permissible errors of closure for different classes of work? p. 160, § 227. 33. Discuss the duties of the different members of a transit party. p. 161.

Exercise Ts–4.

Transit Survey of a Small Area.

Reference: Chapter XIV, p. 145.

Equipment: See Art. 204, p. 145. If the party consists of four men the chainmen should divide between them the equipment of the axeman and flagman.

Directions: Make a survey of a small tract of land, locating all important features such as boundaries, buildings, and fences. Use the direct angle method of running transit lines; *double* all transit line angles, but do *not* double angles in locating details. *Follow carefully* the method of procedure given in *Article* 220 (*b*), page 154.

Note: At the beginning of this exercise it is well for the instructor to take each party over the tract to be surveyed, discussing where to run the transit lines (p. 149), and choosing, tentatively, places for transit stations (p. 148). It should be clearly understood what details are to be located, though the choice of method for locating each point may be left to the student. Methods of marking guard stakes, of keeping notes, of locating details and other questions pertaining to field work suggested in the three preceding exercises should be discussed thoroughly before beginning this exercise.

Exercises similar to this but involving *different* methods of running transit lines should be given also. It is better to make several small surveys by different methods than to make one large survey in which only one method of running transit lines is used.

GROUP Tp.

SPECIAL PROBLEMS IN TRANSIT SURVEYING.

The first seven exercises in this group are illustrations of geometrical and trigonometrical problems which occasionally arise in transit surveying, but which are of too infrequent occurrence to be considered a part of routine field work. The remaining three exercises are special problems in staking out work.

Exercise Tp–1.

Practice in Triangulation.

Reference: Chapter XVI, page 191.

Equipment: Transit, reading preferably to 30 or 20 seconds.

Directions: 1. Establish several tripod signals similar to that described on page 198, § 252. This should be done once for all by the whole class. 2. Measure the angles at each station according to the method described in § 250. Keep notes according to form on p. 197.

Suggestions: Each man in the squad should measure as many angles as time permits, using different transits if practicable. Limits of error should be established by the instructor. See p. 199, § 253. If desired, a base line may be laid out and a regular network of triangles established, although it is probably better to leave this until a regular survey is made, as the main object of this exercise is to accustom the student to the method of measuring angles.

Questions: 1. What is meant by triangulation and a network or system of triangles? p. 191. 2. When would triangulation be employed? § 244 (a). 3. How large an area may be covered by triangulation in *plane* surveying? p. 191, § 244. 4. Give some of the sources of error in triangulation. p. 191. 5. Give some of the things to be considered in the choice of stations. p. 192. 6. What are some of the things to be considered in choosing a place for a base line? p. 193. 7. If the base line is laid off on a railroad track, how may the ends of the base be transferred to points not on the railroad? Bottom of p. 193. 8. When are new or additional base lines introduced in an extensive survey? 9. What considerations govern the length of the base line? p. 194. 10. Give different methods of measuring a base line. p. 194. 11. If it is impossible to establish a single line of sufficient length for a base line, how would you proceed? *Remark*, p. 193. 12. What angles are measured in triangulation? p. 194. 13. Give the sources of error which should be eliminated in the measurement of angles. p. 194, § 250. 14. Give a method of procedure involving the method of repetition. p. 195. 15. Give some practical suggestions for measuring angles. p. 196. 16. Give suggestions for keeping field notes for triangulation. p. 198. 17. Give some practical suggestions for constructing signals. p. 198. 18. What should be the diameter of the mast? p. 199. 19. What errors are allowable in centering a mast over a station? p. 199. 20. What is meant by the eccentricity of a station? Give an illustration. p. 199. 21. Give examples of the accuracy attained in actual practice. p. 199, § 253. 22. How may trigonometric leveling be combined with triangulation? p. 200.

Exercise Tp–2.

To Prolong a Straight Line through an Obstacle.

References: Page 219, §§ 276, 277.

Equipment: Transit, steel tape, stakes, hatchet, sight poles, and chain pins.

Directions: 1. Drive two stakes, *A* and *B*, from 150 to 200 feet apart. 2. Prolong this line through an imaginary obstacle by the second method of § 277 (a), p. 220. 3. Check by the third method. 4. After the work has been checked by the third method, sight along the line through the imaginary obstacle as an additional check.

Field Notes: Make a complete sketch showing all angles and distances measured or laid off. Show the error made in alignment.

Suggestion: For class work an imaginary obstacle is better than a real obstacle, as it permits the check of step (4) above. If time permits, however, it is well to repeat the problem, running a line through a real obstacle instead of an imaginary one.

Questions: 1. When is the rectangle method of Fig. 277 (a) a satisfactory one to use? 2. How can short backsights be avoided in the rectangle method? 3. What is the advantage of the equilateral-triangle method as compared with the third method of § 277? 4. What is the sole advantage of the third method? 5. Give practical suggestions for laying off the angles.

Note: Problems Tp–2 to Tp–6 are special cases of triangulation, and if great accuracy were required refined methods of measuring base lines and angles would be employed. It is sufficient, however, for class work, to dispense with this, using only such precautions as are taken in ordinary transit surveying.

Exercise Tp–3.

To Run a Line between Two Given Points when an Obstacle Intervenes.

Reference: Page 221, § 277 (b).

Equipment: Transit, tape, hatchet, stakes, and sight poles.

Directions: 1. Drive two stakes *A* and *B* from 200 to 300 feet apart. 2. Imagine an obstacle about half way between them, and run a line from *A* to *B* by the first method of Fig. 277 (b). 3. Check by the second method of Fig. 277 (b). 4. Sight from *A* to *B* as a final check.

Field Notes and Suggestions: See preceding problem.

Questions: 1. Draw a sketch illustrating a third method. Compare the two methods of Fig. 277 (b).

Exercise Tp–4.

To Measure between Two Points when One is Inaccessible.

Reference: Page 222, § 277 (c).

Equipment: Transit, steel tape, hatchet, stakes, sight pole, and chain pins.

Directions: 1. Drive two stakes *A* and *B* from 200 to 300 feet apart, and assume *B* to be inaccessible. 2. Find the distance from *A* to *B* by the first method, Fig. 277 (c). 3. Check the distance *AB* by the second method. 4. Measure the distance *AB* with the tape as an additional check.

Field Notes: 1. Make a sketch showing all angles and distances measured or laid off. 2. Arrange computations systematically, and give the discrepancy between the lengths of *AB* as found in steps (2) and (3) and its length as found by measurement with the tape.

Questions: 1. Compare the first and second method. 2. Give a third method that may be used when both ends of the line are accessible. 3. How may each of the three methods be checked without resorting to a different method? 4. Explain by means of a sketch how to measure the distance between two given points when one is invisible from the other and is also inaccessible. p. 223.

Exercise Tp–5.

To Measure between Two Points when Both are Inaccessible.

Reference: Page 223, § 277 (e).

Equipment: Transit, steel tape, stakes, hatchet, chain pins, and sight pole.

Directions: 1. Drive two stakes, *A* and *B*, from 200 to 400 feet apart, and assume both points to be inaccessible. 2. Lay off a convenient base line *CD*, and find by triangulation the distance *AB* as explained in § 277 (e). 3. Measure the distance *AB* with a tape as a check.

Field Notes: 1. A complete sketch showing all distances and angles measured or laid off. 2. A systematic arrangement of all computations. 3. Give the discrepancy between the computed length of *AB* and its length as measured with the tape.

Suggestions: In this problem it is well to measure the angles and the triangles by the method of repetition. Doubling the angles will be sufficient unless the base line is measured with great accuracy, when the method on p. 195 may be employed.

Exercise Tp–6.

To Measure the Height of an Inaccessible Point.

Reference: Page 223, § 277 (f).

Equipment: Transit, steel tape, hatchet, stakes, chain pins, and sight pole.

Directions: 1. Find the height of some inaccessible point as the top of a flag pole, a point on a high building, or some other definite point, by the method explained in § 277 (f). The elevation of the inaccessible point should be determined with reference to some definite point or bench mark near the ground. 2. Repeat the problem as a check, using a different base line.

Field Notes: A sketch showing all angles and distances measured. A systematic arrangement of all computations. Give the discrepancy between the first and second results.

Suggestion: If desired, two or more parties may work simultaneously determining the elevation of the same inaccessible point, and thus save the time required for repeating the exercise as a check.

Note: Notice that the height required is measured from a point on the ground and not from the supporting axis of the telescope. This involves finding the height of the supporting axis with respect to the point on the ground, and this may be found either by the vertical angle method, or, if preferred, by the use of the leveling rod.

Exercise Tp–7.

Perpendiculars and Parallels.

(Exercise for the blackboard and notebook.)

Reference: Page 224, § 278.

Directions: Explain by means of sketches the following methods:

1. To establish a perpendicular to a given line from any given point; (a) when the given line and the given point are both accessible; (b) when the given line is accessible, but the given point is inaccessible; (c) when the given point is accessible, but the given line is inaccessible. 2. To establish a line through a given point parallel to a given line; (a) when the given line and the given point are both accessible; (b) when the given line is accessible, but the given point is inaccessible; (c) when the given point is accessible, but the given line is inaccessible.

Exercise Tp–8.

To Stake Out a Building.

References: Page 209, § 266; also p. 158, § 224.

Equipment: Transit, tape, hatchet, stakes, sight pole.

Directions: 1. Drive two stakes *A* and *B* from 300 to 400 feet apart. Let these represent merestones which determine a street line. 2. Set stakes for the house whose dimensions are given on p. 183, making the front of the house parallel to and

30 feet from the street line AB and at some fixed distance from A measured along the street line.

Field Notes: Make a complete sketch similar to that on p. 210, showing all measurements made, dimensions of the house and the location of reference points; indicate also all points where the transit is set up. Give the discrepancy, if any, between the lengths of the diagonals of the reference rectangle.

Suggestions: 1. As it is usually impracticable in class work to actually set batter-boards, a stake should be driven wherever a point would be fixed on a batter-board. 2. Before beginning the problem, the student should make a rough sketch and plan the work so that it may be done in the shortest time without sacrificing accuracy.

Questions: 1. Give some general suggestions for staking out work. p. 158, § 224. 2. What is the usual method of setting batter-boards, and at what elevation? p. 208, §§ 265, 266. 3. Assuming that the top of a foundation will be wholly below the existing surface of the ground so that when the building is first staked out it is impossible to set the batter-boards at the proper elevation, how would you proceed? 4. Give the general method of staking out a building. p. 209. 5. Sketch another method which is as good as, or better than, the one used for staking out the house on p. 210. 6. Where should reference points be placed? § 266 (b). 7. Give at least two or three different methods for staking out a building whose front is on line with an existing building.

Questions on Staking Out a House Lot, a Highway, a Retaining-wall, an Abutment, and a Tunnel: 1. Give the general method of staking out a house lot. p. 210. 2. Give different methods of marking the corners of the boundaries. p. 211. 3. Give the general method for staking out a highway, together with some practical suggestions. p. 212. 4. Explain the general method of giving lines for a retaining-wall. p. 213. 5. Which lines of a retaining-wall are usually staked out? 6. How are lines given for an excavation? p. 213. 7. When retaining-walls are built in sections, how may they be staked out? p. 213. 8. When walls are on a curve, how are stakes set? p. 214. 9. Illustrate by a sketch how you would set stakes for a wing abutment. 10. How would you proceed in the preceding question if the face of the abutment is in the water where the transit cannot be set up? 11. Explain the general method of giving the line for a tunnel. 12. When the preliminary straight line between the ends of a tunnel cannot be run because of obstacles, how would you proceed?

Note: If time permits, additional exercises suggested by the above questions may be given in staking out work.

Exercise Tp–9.

To Locate Piers for a Bridge.

References: Page 215, § 275, and Chapter XVI, p. 191.

Equipment: Transit, tape, spring balance, thermometer, ax, stakes, leveling rod, sight poles.

Directions: 1. Assume two points *A* and *B* from 400 to 600 feet apart; let these points determine the axis of the bridge. 2. Lay off base lines of suitable lengths at *A* and *B*. 3. Find the distance from *A* to *B*, and locate a pier half-way between them according to the method explained in § 275 (b) and (c). 4. After the center of the pier has been established, not before, measure the distances from this point to each end of the axis as a check on the computed values.

Field Notes: 1. Make a large, open sketch showing the base lines, the axis of the bridge, the values of all angles measured and the values of all angles turned off in the location of the pier. 2. Keep the field notes for the triangulation according to the form on p. 197. 3. Arrange computations for triangulation according to the form on p. 399, or, better still, that on p. 400. The form used in determining the probable error of the base line is given on p. 59.

Suggestions: 1. Select a place for this exercise where the stakes for each base line may be set with their tops on a level. As considerable time is necessary for setting these stakes, they may be driven once for all and used by different parties. The work may be further shortened by permitting one party to work on one side of the imaginary river and the other party to work on the other side. The work may be changed for different parties by changing slightly the lengths of the base line or the distance between the two stakes *A* and *B*. When the time comes for establishing the center of the pier, it will be convenient to do this on a board platform (a table turned upside down will answer the purpose).

2. If desired, the triangulation for determining the length of the axis *AB* may be done on one day, the necessary computations made in the evening, and the angles turned off for locating the pier on another day. Of course, if time permits, two or more piers may be located instead of one.

Questions: 1. Give the two steps involved in locating a bridge pier. p. 216, § 275. 2. Give an ideal method. § 275 (a).

3. Is this method often practicable? 4. Give the general method. § 275 (b). 5. Why is it undesirable to choose both base lines on the same shore and on the same side of the bridge, or on opposite shores, one above, the other below the bridge? 6. Why is it not worth while to lay off the base line at right angles to the axis? 7. Give suggestions for referencing and protecting hubs. p. 217. 8. Give suggestions for choosing the location and the length of a base line. pp. 217 and 193. 9. When there are several piers, are they always located from the same point on a base line? p. 217. 10. What is done when the conditions on the shore are unfavorable for base-line measurement? p. 217. 11. What should be the limit of error for the sum of the most probable values of the three angles in each of the main triangles? p. 218. 12. Describe the method for laying off the angles. p. 218. 13. When a pier is built in a movable caisson, how is the latter kept in place? 14. How does the method of giving points for a rectangular pier differ from that used for round piers? p. 218.

Exercise Tp–10.

To Stake Out a Circle with a Transit and a Tape.

Reference: Page 204, § 263.

Equipment: Transit, steel tape, ax, and stakes

Directions: Stake out a complete circle whose radius (preferably not less than 300 feet) will be given by the instructor.

Field Notes: 1. All computations neatly arranged on the right-hand page. 2. Before beginning to stake out the curve, work up the field notes in a form similar to that for deflection angles on p. 174. See also *suggestion* (3), p. 207.

Suggestions: In this exercise C may be taken as 100 feet, and R is given, hence D is easily calculated. In the field work, follow the general method outlined in step (4), p. 206, and also the directions for "picking up" a tangent, p. 206.

If desired, additional exercises may be given, as, for example, to connect two tangents by a circular arc (see p. 206, § 263 (*f*)). If, however, the student is to have a course in railroad curves, it is better to do all such work in connection with that course.

Questions: 1. Define tangent, angle of intersection, deflection angle, and chord. 2. Prove that $T = R \times \tan \frac{1}{2} I$. 3. Prove that $\sin D = \frac{1}{2} C \div R$. 4. Prove that $T = (C \times \tan \frac{1}{2} I)$

$\div 2 \sin D$. 5. Define sub-chord, sub-deflection angle, length of curve, and degree of curve. 6. How is the length of curve usually found? 7. What is the degree of curve in this exercise? 8. What is the length of curve in this exercise? 9. If 50-foot chords were used in this exercise, what would be the new values for the deflection angle and the sub-deflection angle? 10. Describe the general method of running in a circular curve between two tangents. p. 206. 11. Explain the method of "picking up" a tangent, giving two rules to be kept in mind. p. 206. 12. Prove that if a transit is at 3, the backsight at 2, and the vernier at $2D$, the line of sight may be made tangent to the curve by setting the vernier at $3D$. 13. Why should the index reading for $P.T.$ equal $\frac{1}{2} I$?

GROUP L.

EXERCISES IN LEVELING.

The first five exercises in this group offer the student an opportunity to learn the use of the level and the leveling rod, and to study the sources of personal and instrumental errors. The next three exercises afford practice in differential leveling and in profile leveling, while the ninth exercise is a class-room discussion of errors in leveling. The remaining three exercises take up the use of the hand level, trigonometric leveling and barometric leveling.

Exercise L 1.

Setting up the Level.

References: Page 226, also 544.

Equipment: A level for each student, or as many levels as are available.

Directions: 1. Set up a level as directed on p. 226. 2. Perform each of the three steps in the experiment described on p. 227.

Questions: 1. What is the shape of the interior surface of the glass tube of a spirit-level? p. 544. 2. Upon what does the sensitiveness of a bubble depend? p. 544. 3. Can a bubble be too sensitive for ordinary work? 4. What is the fluid used for the level-bubble? p. 544. 5. Why does the length of the bubble change from time to time, and is it more sensitive when long or when short? p. 544. 6. What is the *axis of a bubble tube?* p. 544. 7. What should be the first precaution taken in setting up a level? p. 251, § 322, also 271, § 349. 8. If it is impossible to set up a level so that the bubble will remain in the center for all positions of the telescope, what does this indicate?

Additional Questions: Many of the questions asked in Exercise T-1 (Setting up the Transit) may also be asked in connection with setting up the level. If the construction of the telescope has not already been discussed in connection with transit work, the instructor should explain briefly the different parts of the telescope (see photograph, p. 551), or, if thought best, to add to the questions given above those on pages 96 and 97 of this book.

Exercise L-2.

Reading the Leveling Rod.

References: Pages 227 to 232.

Equipment: Several leveling rods for each squad, including targets with scales and targets with verniers.

Directions: 1. Set the target at random without extending the rod. Read and record the setting of the target. 2. Record the instructor's reading. 3. Repeat for a number of settings for a "low rod." 4. Apply to each rod the two tests described in § 286, p. 232. 5. Read and record several settings for a "high rod."

Suggestions: It is well for an instructor to set the targets at random on several rods, and to require the members of his squad to read these settings in rotation. He should take pains to have some of the settings near the "danger points" where are likely to occur such common mistakes as are noted at the bottom of p. 229 and on p. 231. The exercise should be continued until each member of the squad can read any target setting, for either a "low" or a "high" rod.

Questions: 1. What two methods are there of reading a rod in leveling? § 281, p. 227. 2. What is the difference between a target with a scale and a target with a vernier? 3. How can you estimate a reading to thousandths on a target with a scale? 4. What are some of the common mistakes in reading a leveling rod, and what points should be fixed in mind as "danger points"? p. 229. 5. Explain the difference between the methods of reading a target with a scale and a target with a vernier. § 285. 6. Explain how to read a "high rod," and the tests which should be applied to every rod when using it for the first time. §§ 284 and 286. 7. What are the different sources of error or mistakes in taking a "high rod" reading? § 284 (a), (b). 8. Into what two classes may leveling rods be divided? p 571. 9. Explain the difference between the New York and the Philadelphia rods. 10. What kind of target is preferable for long sights? p. 572. 11. What is an *angle target*, and for what purpose was it designed? p. 572 and p. 270. 12. Name two special forms of leveling rods. p. 572, § 573 (b). 13. Describe a plumbing level. p. 573. 14. Could stadia rods, p. 574, be used as self-reading leveling rods?

Exercise L-3.

To Find the Probable Error of Sighting and of Setting a Target.

Reference: Page 270, § 348.

Equipment: Level, leveling rod, tape, ax, stakes.

Directions: 1. Set up the level, and drive stakes approximately in line, at distances of 100, 200, 300, and 400 feet respectively from the level. 2. Hold the rod on the stake at the 100-foot point, set the target so that its center coincides with the line of sight, and record the reading. 3. Move the target up or down a foot or more out of the line of sight and again set it as accurately as possible, holding the rod on the same point on the stake. 4. Repeat the work until five independent settings of the target have been made on each of the four stakes. 5. From the five readings at each stake find the probable error for that stake as explained on pp. 15 to 19.

Field Notes: Record the readings for the different stakes in separate columns. Use the form on p. 19 for determining the probable errors. Arrange all computations systematically.

Suggestions: Set two legs of a tripod in a line parallel to the general direction of the line of stakes, and see that all three legs are reasonably firm before leveling up. When the sun is shining set the level up in the shade. Take every precaution to avoid disturbing the level during the exercise, and be careful to have the bubble in the center of the tube during each sight. The bubble may often be brought into the center by pressing down slightly with the finger on the telescope.

Questions: 1. Give some of the sources of error in sighting. p. 270. 2. What is the effect of refraction? p. 273. 3. What is the best time of day for precise leveling? Bottom of p. 272, also (3) p. 278.

Note: This exercise may be repeated, the readings being made directly from the level without the use of the target. The probable errors at each distance for the two methods may then be compared, thus giving an idea of the relative accuracy of target readings and of direct readings. See p. 271.

Exercise L-4.

Comparison of Readings Taken With and Without the Target.

Reference: Experiment, p. 271.

Equipment: Level, leveling rod, tape, ax, and stakes.

Directions: 1. Set up the level, and drive stakes at distances of 50, 100, 150, 200, 250, 300, 350, and 400 feet from the level. 2. Take a rod reading on the top of each stake, first without, then with, the target. 3. Record all readings and state conclusions as to how closely one can read at different distances without using the target, and how such readings are affected by distance.

Note: Conclusions should not be drawn from too few data, but by tabulating the results obtained by *all* the members of a class a comparison of the two methods of reading the rod may be made.

Exercise L-5.

To Test the Sensitiveness of a Level Bubble.

Reference: Page 545, § 567 (a).

Equipment: Level, leveling rod, tape, ax and stakes.

Directions: 1. Set up the level, and drive a stake 200 feet away. Test the sensitiveness of the bubble with the leveling rod held on this stake as explained on p. 545. 2. Repeat the test, holding the rod at distances of 300 and 400 feet from the level.

Field Notes: A complete record of the results obtained from the different tests with the mean value of one division in seconds of arc.

Suggestions: See page 545.

Questions: 1. How could a bubble tube other than a telescope level be tested? p. 545. 2. What is a level-trier? 3. Show by means of a sketch that $R = \frac{nd}{h} D$, p. 545. 4. Find the radius of curvature of the bubble tube on the level used in this exercise.

Exercise L-6.

Differential Leveling.

(A Study of the Theory.)

References: Pages 234 to 242.

Equipment: Level, leveling rod.

Directions: 1. Select two points several hundred feet apart, one of them 40 or 50 feet higher than the other. 2. Run a line of levels from the first point to the second and back again to the first point.

Field Notes: Use Form B on p. 240.

Suggestions: For this first exercise in differential leveling, it is well to choose a place where a complete circuit can be made in five or six set-ups. The work may then be repeated, the levelman and the rodman interchanging positions. Too much emphasis should not be placed on the niceties of field work, as the object of this exercise is to acquaint the student with the *theory* of leveling. In the next exercise the methods of *field work* may be studied, and greater precautions taken to obtain accurate results.

Before going into the field, it is well for the instructor to put a sketch on the blackboard similar to that on page 238, with backsight and foresight readings indicated in simple numbers, and then to require each student to work out the notes for this sketch in a form similar to that on page 240. It is also well to discuss the questions given below just before beginning the field work of this exercise.

Questions: 1. What two kinds of work are done in leveling? p. 234. § 288. 2. Define datum line and datum plane. 3. Is a level surface a plane surface? 4. What is taken as a convenient datum the world over? 5. Is the sea level the only datum used? 6. Define bench or bench-mark. 7. Define station, and point out the difference between a station in transit surveying and a station in leveling. 8. Define plane of sight. 9. What are the two essential steps in leveling? p. 235. 10. Is there any difference in practice between measuring *up* to the plane of the sight and measuring *down?* 11. Define height of instrument. 12. Define backsight. 13. How is a backsight used in determining height of instrument? 14. Define foresight. 15. Why are "backsight" and "foresight" unfortunate terms? p. 237. 16. What two terms are sometimes used in place of backsight and foresight? 17. What is the object of backsighting and of foresighting? p. 237. 18. What abbreviations are used in leveling? 19. What two formulas express the theory of leveling, and to what two steps in leveling do they correspond? p. 237. 20. Explain how the elevations of points above the plane of sight may be found. 21. Explain by means of a sketch the general theory of leveling when more than one set-up is necessary. § 299 (c). 22. Are stations in leveling necessarily in a straight line, or may they be taken anywhere? 23. How may the two steps in leveling be remembered? Remark, p. 238. 24. What is an intermediate station and its distinguishing characteristic? p. 238. 25. What is a turning-point, its distinguishing characteristic, and how did it get its name? 26. May a station or a bench-mark be used as a turning-point? p. 239. 27. What are the first and last points sighted at in leveling usually considered? p. 239. 28. Explain why an error made at a turning-point is much more serious than an error made at an intermediate station. 29. What are the advantages and disadvantages of Form A for leveling notes? p. 239. 30. Comment on Form B for leveling notes. p. 240.

Exercise L-7.

Differential Leveling.

(A Study of Field Methods.)

References: Pages 248–258; 260–263.

Equipment: Level, leveling rod, ax.

Directions: From some assumed point as a bench-mark run a line of levels to a second point and return, making a circuit of about 10 set-ups. Keep field notes according to Form B, p. 240.

Suggestions: The theory of leveling having been studied in the preceding exercise, special attention should be paid in this exercise to the methods of field work, especially to those precautions which are necessary for accurate work. If desired, several parties of two men each may run levels over the same circuit, checking every three or four set-ups at a common bench-mark established by the instructor. *It is well to establish a number of permanent bench-marks* differing as much as practicable in elevation, as these benches will be of use later in the course in connection with barometric leveling, trigonometric leveling, and other exercises. If desired, this exercise may be repeated, *all* sights being taken on a self-reading rod, no use being made of the target.

Questions: 1. Give the signals used in leveling. p. 248. 2. How may the elevation of the starting-point be obtained? p. 249. 3. How may any elevation be assumed and the notes afterward corrected? Illustration, p. 250. 4. Why should the rodman hold his rod a second time after clamping the target? 5. What should be the lengths of foresights and backsights in ordinary work for the best results? 6. What is the first precaution in setting up a level? p. 251. 7. In going up, or down, hill, how can one avoid taking unequal sights? 8. What is a common mistake of the beginner in setting up a level on steep slopes, and how can this mistake be avoided? p. 251. 9. What chiefly determines the location of turning-points? p. 252. 10. In choosing an object for a turning-point, what should be kept in mind? *Remark*, p. 252. 11. Describe a form of turning-point sometimes used. § 323 (b). 12. Describe two methods of holding a leveling rod. p. 252. 13. Give a method of making sure that the rod is plumb. pp. 252, 270, § 346 (c). 14. Give examples of bench-marks both permanent and temporary. p. 253. 15. Where should bench-marks be established? p. 253. 16. What is the only method of checking field work in leveling? § 329. 17. If sixteen set-ups are necessary to complete a circuit of levels, what should be the approximate limit of error? i.e., the difference between the elevation of the starting-point and the elevation of the same point as determined at the completion of the circuit. p. 254. 18. Give some suggestions for working rapidly in leveling. p. 255. 19. What should be the average speed for class work? *Remark*, p. 255. 20. Give suggestions for the levelman concerning the following points: p. 260. Choosing place for level; leveling on steep slopes; watching the bubble; unnecessary clamping; horizontal cross-hair; sunshade; disturbing instrument; definite signals; adjustment of level; effects of heat and wind; care of the level. 21. Give suggestions for the rodman concerning the following points: See p. 261. Choosing turning-points; length of sights; holding the rod; moving the target; clamping the target; testing the rod; common mistakes in reading; care of the rod. 22. Give duties of levelman; of rodman. p. 263.

Exercise L-8.

Profile Leveling.

References: Page 242, § 306; p. 251.

Equipment: Level, leveling rod, stakes, tape.

Directions: Drive a row of stakes 50 feet apart for a distance of about 1000 feet. Run a line of profile levels, taking the elevation of the ground at each stake. At all intermediate stations read the rod from the instrument without the use of the target, but at turning-points use the target. When the elevation at the last stake has been determined, run back over the line to the starting-point, taking turning-points only, and thus checking the work of the whole exercise.

Field Notes: Keep field notes according to Form E, p. 256, and check the arithmetical work by the method explained on p. 242.

Suggestions: If desired, several parties of two men each may work along the same line of stakes, checking at frequent intervals on the same bench-marks established by the instructor. In this case it will be unnecessary to run back over the line as a check.

Questions: 1. What is an intermediate station? p. 238. 2. Is it necessary to take the elevations at intermediate stations as accurately as at turning-points? 3. Does the rule for checking notes on p. 242 afford any check for intermediate stations? 4. Explain a form of notes that does give a check on intermediate stations. § 303 (e). 5. What are the advantages of Form C, p. 241, for profile notes? 6. In ordinary work how closely should the rod be read at intermediate stations, and should this reading be taken with or without the target? p. 253.

Exercise L-9.

Discussion of Errors in Leveling.

(Exercise for the Class-room.)

Questions: 1. Give some of the sources of error in leveling. p. 268. 2. How may the errors of adjustment be largely eliminated? 3. What precautions should be taken when the bubble is sluggish? p. 268. 4. What is the error in the movement of the object-glass slide, and how may it be eliminated? p. 268, also p. 602, § 586. 5. What is the error due to a defective joint in the leveling rod? p. 269; also *Remark*, p. 232. 6. Give some of the sources of error in manipulating the level. p. 269. 7. How may the error due to the rod being held out of plumb be avoided? 8. Why is this error compensating on turning-points when leveling up and down hill over rolling country? 9. Why is this error not compensating in leveling up hill only or down hill only? 10. Why is it not best to wave the rod when the reading is two feet or less from the bottom of the rod? 11. What errors are due to the accumulation of dirt or grit on the base of the rod or in the joints? 12. Give some of the sources of error in sighting. 13. Explain why the settling of the instrument between the backsight on one turning-point and the foresight on the next is a source of cumulative error. How may this error be avoided? p. 271. 14. What precautions should be taken to avoid errors due to disturbance of the instrument? p. 272. 15. Explain why the settling of the turning-point is a source of cumulative error. 16. Explain why the sun shining on the instrument is a source of cumulative error. p. 273. 17. What is the error due to curvature? p. 272. 18. What is the error due to refraction? p. 273. 19. What is the effect of combining these two errors? p. 273. 20. Give common mistakes in recording. 21. How may errors in computing be discovered? p. 274. 22. How may personal errors be partially eliminated? 23. Recapitulate the most important precautions taken to eliminate errors: (a) mistakes; (b) constant errors; (c) accidental errors. p. 275. 24. How may the precision of leveling be judged? p. 275. 25. How may the total error of a line of levels be expected to vary? p. 276. 26. In a common formula for allowable error what is the usual value of C? p. 276. 27. If a circuit of levels four miles long be completed, what should be the permissible error if the coefficient C is .04? 28. Give some of the most important directions contained in instructions for accurate leveling (p. 277) as regards: number of rodmen; method of rodmen keeping independent readings; weather conditions; foresights and backsights; duties of the bubble tender; adjustment of level; steel turning-points; plumbing levels; permanent bench-marks; permissible error. 29. Give the method of procedure when two rodmen are employed. p. 279. 30. In crossing a wide river explain how the method of reciprocal leveling may be used. p. 243. (See also exercise in reciprocal leveling, page 63 of this book.)

Exercise L-10.

Use of the Hand Level.

Reference: Page 233.

Equipment: Hand level and hand leveling rod, or two hand levels and two rods.

Directions: Find the difference in elevation between two points several hundred feet apart, by means of a hand level, using the second method of § 287, p. 233.

Field Notes: A sketch showing the different steps and the final difference in elevation.

Suggestions: If possible, the leveling should be done between two bench-marks whose elevations have been determined previously by differential leveling, and the difference in elevation should be compared with that obtained by the more accurate method. The party should consist of two men; and, if desired, each may be equipped with a hand level and a 5 foot rod, so that first one and then the other uses the hand level, alternating, as explained in "Routine of the Field Work." bottom of p. 351. If only one hand-level is used, the work may be repeated, the levelman and rodman interchanging positions, and running back over the line to the starting-point.

Questions: 1. How can rough work be done without the use of a rod? p. 233. 2. What is the difference in method between leveling up hill and leveling down hill? p. 233. 3. For what is the hand level chiefly used? p. 233.

Exercise L-11.

Trigonometric Leveling.

References: Pages 244, 264.

Equipment: Transit, leveling rod, and steel tape.

Directions: 1. Find the difference in elevation between two points *A* and *B*, by setting up the transit near *A* and using the first method of "Trigonometric Leveling" on pp. 244, 264. 2. Repeat the exercise, setting up the transit near *B* instead of *A*, the two men in the party interchanging positions.

Field Notes: A sketch showing the method, with all distances and angles; also all computations systematically arranged.

Suggestions: 1. In this exercise the horizontal distances from the transit to each of the two points *A* and *B* is measured with a tape, although in most field work where this method is used, distances are found either by triangulation or with the stadia. If possible, the two points *A* and *B* should be bench-marks whose elevations have been determined previously by spirit leveling, and the difference in elevation obtained in this exercise should be compared with that obtained by spirit leveling. 2. The shortest method is to set the transit up with the end of the supporting axis approximately over either *A* or *B*. If this is impracticable, it will be necessary to determine the height of the supporting axis by a backsight on the nearer station. See *Remark* (b), p. 244.

Questions: 1. Explain the first method of trigonometric leveling. p. 244. 2. In this method, if elevations of points are required with reference to some datum, what is the first step after setting up the transit? p. 244. 3. If the horizontal distances from the transit to the point whose elevation is required cannot be measured directly, how would you proceed? p. 244. (See also Exercise for Determining the Height of an Inaccessible Point, p. 223.) 4. In finding the elevation of any point on the ground with reference to a point under the transit, how would you use a sight-pole in place of a leveling rod? p. 264, *Practical Hint* (a). 5. How may time be saved in computing elevations from vertical angles? p. 264. 6. Show what error may be expected for sights of 200 feet if the horizontal distance is correct but the error in the vertical angle is one minute, ignoring instrumental errors. p. 264. 7. For the same length of sight, what would be the error if the vertical angle of, say, 8 degrees 40 minutes is correct, but the horizontal distance is in error as much as one foot? p. 264. 8. Explain the second method of trigonometric leveling. p. 264. 9. Is the first or the second method most used in topographic surveying, and how are the distances determined? p. 264. 10. How may triangulation and trigonometric leveling be combined, and how do the results compare with spirit leveling? p. 200.

Exercise L–12.

Barometric Leveling.

References: Page 245, § 313; p. 265, § 343.

Equipment: Aneroid barometer, thermometer.

Directions: 1. Hold the barometer on a bench-mark whose elevation has been determined previously by spirit leveling, and set the altitude scale of the barometer to correspond to the elevation of that bench-mark. 2. Without disturbing the altitude scale take readings of the barometer at two or more bench-marks whose elevations are known, and compare the elevations as found by the barometer with the elevations as found by spirit leveling. 3. Repeat the problem but ignore the altitude scale, and proceed as directed on p. 265, § 343 (a). 4. Compare results with those obtained by spirit leveling and with those found by the use of the altitude scale.

Field Notes: Keep a full record in tabular form of the readings of the altitude scale, of the barometer readings in inches, and of the temperature at each bench-mark. Also a systematic arrangement of the computations for reducing readings to altitudes.

Suggestions: In this exercise it is desirable that there should be a considerable difference in elevation between the successive bench-marks selected, and that these elevations should have been determined previously by spirit leveling. The results as obtained by different students going over the same line of bench-marks may be tabulated by the instructor and shown to the class, thus giving an idea of the accuracy to be obtained in barometric leveling. It is well also to use several different aneroid barometers, and, if desired, readings may also be taken with mercurial barometer.

Questions: 1. Describe the aneroid barometer. p. 264. 2. What is the average reading of a barometer at sea level, and the average rate of fall in ascending above the sea level? p. 245. 3. What are the atmospheric sources of error? p. 245. 4. How does temperature affect barometer readings? p. 246. 5. Compare two classes of barometric formulas. p. 246. 6. In ordinary work what sources of error are usually ignored? Bottom p. 246. 7. What are some of the instrumental sources of error? p. 265. 8. Give the method of procedure where single observations are taken. p. 265. 9. Explain the method of simultaneous observations. p. 266. 10. What are the ordinary limits of error? p. 267.

GROUP Lp.

SPECIAL PROBLEMS IN LEVELING.

The exercises in this group deal with various problems in leveling such as setting grade stakes, estimating cut and fill for grading, and staking out a vertical curve.

Exercise Lp–1.

Reciprocal Leveling.

Reference: Page 243.

Equipment: Level, leveling rod, ax, and stakes.

Directions: 1. Drive two stakes *A* and *B* from 300 to 400 feet apart. 2. Imagine these stakes to be on opposite banks of a river so that the level cannot be set up between them, and find the difference in elevation between the tops of the stakes by the method of Reciprocal Leveling. p. 243. 3. Repeat the work, levelman and rodman interchanging positions. 4. Set up the level approximately one-half way between the two stakes, and check the mean result obtained by reciprocal leveling.

Field Notes: Make a sketch showing the approximate distance between stakes as obtained by pacing, the positions of the level and all elevations. See Figure, p. 598. In addition keep the level notes on the left-hand page in the usual form. p. 240.

Questions: 1. Why does reciprocal leveling tend to eliminate the error due to adjustment, the error due to curvature, and refraction? pp. 598, 599, 273.

Exercise Lp–2.

To Set Stakes on a Grade Between Two Fixed Points.

(Special Method.)

References: Page 243, § 310; p. 258, § 334; p. 280, § 357; p. 282, § 358.

Equipment: Level, leveling rod, ax, and stakes.

Directions: Choose a place where the slope of the ground is uniform for several hundred feet so that the tops of all stakes can be driven to grade, and drive two stakes *A* and *B* several hundred feet apart. 2. Ascertain the difference in elevation between *A* and *B*. 3. Set a line of stakes with their tops on grade between *A* and *B*, and with 25-foot intervals between stakes. Use the grade rod method (see illustration, top of p. 281) and also § 358 (a). 4. Check the work by setting up the level near stake *A* and shooting in the grade as explained in § 357 (d), p. 281.

Field Notes: Number the stations 0, 0 + 25, 0 + 50, etc., and keep the notes in a form similar to one of those on pp. 284, 256.

Suggestions: See *Practical suggestions* on pp. 259, 282, and 281.

Questions: 1. Define grade, and grade rod, and illustrate how the grade rod is calculated. p. 243, and also p. 428. 2. Give five different methods of setting grade stakes. p. 258. 3. Give the general method of procedure in setting grade stakes. p. 259. 4. What is the difference between a true grade rod and a field grade rod? p. 259. 5. How close should stakes be driven in ordinary grading? p. 259. 6. Give some practical suggestions for setting stakes. p. 259. 7. What are two common mistakes which occur in setting grade stakes, and how may errors be detected? p. 259. 8. What additional columns should appear in the field notes? p. 260. 9. What is meant by "shooting in" a grade, and what is the best instrument to use for this method? p. 260, also p. 281. 10. In the method of shooting in grades, why is step 4, p. 281, necessary, and how can this step be avoided? Note, p. 281. 11. What is the object in establishing a permanent foresight in step 5, p. 281? 12. How may a convenient permanent foresight be established? *Suggestion* 2, bottom of p. 281. 13. Is the error involved in setting the target opposite to the center of the object glass likely to be large? p. 281. 14. Suppose the surface of the ground to have a uniform slope which, however, is too far above or below the required grade to permit driving stakes to grade, how would you proceed to shoot in the grade? *Suggestion* 4, top of p. 282. 15. Give some practical suggestions for setting grade stakes for a curb. p. 282. 16. Give the general method of laying out grades for pavements as regards, marking gutter lines; center line; use of templet.

Exercise Lp-3.

To Set Grade Stakes Between Two Fixed Points When the Ground is Uneven.

(General Method.)

Reference and Equipment same as for preceding exercise.

Directions: Repeat the preceding exercise, but select a place where the ground is so uneven that the tops of the stakes cannot be set to grade. Use method 2, p. 258, i.e. top of each stake to be a whole number of feet above or below grade. Mark stakes as directed on p. 260.

Question: 1. What is the chief difference between the methods used in this exercise and that of the preceding exercise?

Questions on Giving Grades for a Sewer: 2. Explain the general method of giving grades for a sewer. p. 283. 3. How closely should grades be given for a sewer? 4. How would you proceed when it is impracticable to give elevations at equal distances along sewer line? p. 283. 5. What rough check should always be employed? p. 283. 6. Why should benchmarks be established? p. 283. 7. Describe a form of grade-pole for sewer work. p. 283. 8. Why work in one direction from down hill up hill or *vice versa?* p. 283. 9. Give two methods of measuring between grade-slats, and why are measurements made parallel to the flow line? p. 283. 10. Explain in detail the notes on pp. 284 and 285. See explanation 286.

Questions on Giving Elevations for a Line of Shafting: 11. Give the general method of giving elevations for a line of shafting. p. 287. 12. Why is it convenient to hold the leveling rod upside-down, and illustrate what is meant by a minus grade rod? p. 287.

Exercise Lp-4.

Use of the Gradienter.

Reference: Page 245.

Equipment: Transit equipped with a gradienter, leveling rod, ax, and stakes. (Transit should be in adjustment for leveling.)

Directions: 1. Select a comparatively level piece of ground, and by means of the gradienter set a row of stakes at intervals of 25 feet with their tops driven to a given grade. 2. Check each stake by the grade-rod method explained on p. 259.

Field Notes: On the right-hand page a description of the work with a comparison of the levels obtained by the two methods and the average discrepancy. On the left-hand page the usual form of field notes. p. 284.

Suggestion: This exercise may be given in connection with Exercise Lp-2 if desired.

Questions: 1. Explain the principle of the gradienter. p. 245. 2. How may the gradienter be used for measuring distances? p. 245.

Exercise Lp-5.

To Estimate Cut and Fill for Grading.

References: Page 287, § 362; pp. 429–433.

Equipment: Level, leveling rod, tape, ax, and stakes.

Directions: 1. Select a plot of ground at least 150 feet square, with a rather uneven surface. If no plot with definite boundaries is convenient, mark out one with stakes. 2. Perform the field work necessary to obtain data for estimating cut and fill for grading according to the method of § 362, p. 287. 3. Assuming that the ground is to be graded to a level one foot below the lowest elevation obtained at any stake set in the preceding step, calculate the total cut in cubic yards.

Field Notes: On the right-hand page draw a sketch showing all stakes with numbers and distances, and on the left-hand page keep the level notes in the usual form. p. 240. Use a system of numbering points like that of Figure 402 (c), p. 341.

Suggestions: Follow the practical suggestions given on p. 287. If desired in the third step above, the finished surface may be assumed at such an elevation as to require both cut and fill. The problem may be further complicated by assuming this surface to be on a slope instead of on a level. As a rule, however, the more complicated work of calculation should be left for the course in office work, and thus time will be saved in the field.

Questions: Give the general method of field work in getting data for estimating cut and fill for grading. p. 287. 2. Give practical suggestions concerning, establishing permanent bench-marks. p. 287; choosing the size of squares. pp. 287 and 432; extra rod readings; system of marking corners; and of laying out squares. 3. Give the general method of setting stakes for grading land. p. 287, § 363. 4. What is the customary method used when the surface of the ground is very uneven, making it necessary to set temporary stakes? *Remark*, p. 288. 5. Give the general method of setting stakes, (a) for a level grade; (b) for a grade that slopes in one direction only; (c) for a grade that slopes in two directions.

Note: If desired problems may be given in setting grade stakes by each of the three methods referred to in the last question above.

Exercise Lp-6.

To Stake out a Vertical Curve.

References: Pages 289–292.

Equipment: Level, leveling rod, ax, and stakes.

Directions: Set stakes for a vertical parabola which shall connect two gradients assigned by the instructor. Use the method of procedure for chord gradients explained on p. 291, § 364 (d).

Field Notes: 1. On the right-hand page make a sketch similar to that on p. 290, giving the necessary data; give also all computations systematically arranged. 2. On the left-hand page record all notes for leveling in the usual form (see p. 284), giving the grade rods and elevations at all points.

Suggestions: If it is desired to drive stakes so that their tops are on grade, this problem must be arranged by the instructor to suit the nature of the ground; e.g., a vertical curve of large radius may be staked out on comparatively level ground, using tall stakes for the highest points on the curve. The student can then judge for himself by the appearance of the curve passing through the tops of the stakes whether or not the work is approximately correct. If this method is followed, however, the fact should be emphasized that it is not the usual method of procedure, but that in most cases each stake is driven, not to grade, but with its top a whole number of feet above or below grade according to method 2, p. 258; or, if this is impracticable, method 3 is followed.

Questions: 1. Give two general methods of finding elevations of points on a vertical curve. p. 289. 2. If the second method is used, why is the vertical scale usually much greater than the horizontal scale? p. 289. 3. Why is the parabola more often used than the circle for vertical curves? p. 289. 4. Explain the method of finding points on a vertical parabola by tangent corrections; by successive chord gradients. p. 290. 5. How may the elevation of any point between stations be found? p. 290. 6. Give two methods of field work for running in a vertical curve. p. 291. 7. Compare the two methods. p. 291. 8. Explain how to make the vertical parabola pass through a point at a given distance above or below I. p. 292, § 364 (g). 9. How would you proceed when the rate of change c and the two grades g and g' are given? § 364 (h). 10. Explain methods of checking computations. Top and bottom of p. 292; also illustration, bottom p. 368.

GROUP Co.

EXERCISES IN THE USE OF THE COMPASS.

Exercise Co–1.

The Error of Sighting and Reading a Compass.

References: Pages 293–295, p. 101, §143, p. 575, § 575.

Equipment: Compass, tape, sight-pole, ax, and stakes.

Directions: 1. Drive a stake *A* and set up the compass over this stake. 2. Drive a stake *B* 300 or 400 feet away, sight at a pole held on this stake, and read the bearing of the line *AB*. 3. Move the compass through an arc of, say, 90°, thus changing the reading of the needle; then, without sighting at *B*, set the compass at the original bearing of *AB*, line in the pole and measure the distance this line of sight passes to one side or the other of the stake *B*. 4. Repeat the work a number of times, changing the reading of the needle and resetting the compass at the same bearing each time. From a number of results thus obtained, find the probable error of sighting the compass, in units of angular measure. (This will require a rough measurement of the distances from stake *A* to stake *B*.) Use a form similar to that on p. 19 for finding the probable error.

Note: The distance that the line of sight passes to one side or the other of the stake should be entered in the column headed "v." When the probable error has been obtained in units of *linear* measurement this quantity divided by the distance *AB* will give (approximately) the tangent of the *angle* which corresponds to that probable error.

Questions: 1. Explain the method of reading bearings. p. 101. 2. Why are the letters *E* and *W* interchanged in the compass box? p. 102. 3. What precaution should be observed in reading bearings? 4. Why is it not advantageous to place telescopes on compasses? p. 576.

Note: Questions concerning bearings asked in connection with Exercise Tr–5, page 32, of this book may be discussed in connection with this exercise also.

Exercise Co-2.

Reading Bearings.

References: Page 101, § 143; pp. 111–113; pp. 541-543; p. 575, § 575.

Equipment: Compass, sight-pole, ax, and stakes.

Directions: 1. Set the compass over a stake A. 2. Drive four stakes, B, C, D, and E, at random, each at least 200 feet from stake A, making a four-sided polygon $BCDE$ with A in the approximate center of this polygon. 3. By sighting at each stake in succession read and record the bearings of the lines AB, AC, AD, and AE. 4. By the method explained on p. 382, § 435, find the values of the angles BAC, CAD, DAE, and EAB, and compare their sum with 360°.

Field Notes: 1. Make a sketch showing the bearing of each line and the angles between lines. 2. Arrange the computations for angles according to the form on p. 383.

Questions: 1. What is meant by the dip of the needle? How is this dip counteracted? p. 541. 2. What is meant by the magnetic declination and the magnetic meridian? p. 541. 3. Define isogonic lines and agonic line. p. 543. 4. What is meant by a west declination? an east declination? In the United States how can you remember whether the declination is east or west for any given place? p. 111. 5. What is the approximate magnetic declination at New York? at San Francisco? at Chicago? See Isogonic chart opposite p. 638. 6. What is meant by local attraction, and give some of the sources of such attraction. p. 543. 7. If something about the person deflects the needle, as, for example, a knife or keys in the pocket, is this, strictly speaking, local attraction? p. 543. 8. Name five variations of declination. p. 541. 9. Give some facts concerning secular variation. p. 541. 10. Give some facts concerning diurnal variation. p. 542. 11. Is annual variation the same as the change per year in secular variation? p. 543. 12. To what are irregular variations due? p. 543. 13. Describe various forms of compasses. p. 575. 14. Upon what does the sensitiveness of the needle depend? p. 575. 15. What precautions should always be taken to avoid dulling the pivot? p. 294, § 366 (3). 16. Give the most important requirements for a good compass. p. 575.

17. What is the difference between a plain compass and a vernier compass? p. 575. 18. What is a prismatic compass? p. 576. 19. Describe three tests for the compass. p. 576. 20. How may a needle be remagnetized? 21. If a compass is to be put away for a considerable length of time, what precaution may be taken in order that the needle may retain its magnetic strength? p. 295.

Exercise Co-3.

Compass Survey of a Polygon.

References: Chapter XXIV, p. 293; also § 566, p. 541; § 575, p. 575.

Equipment: Surveyor's compass, chain or tape, sight-poles, ax, and stakes.

Directions: Drive four or five stakes at random, forming an irregular polygon no side of which is less than 150 feet. Beginning at any stake survey this polygon, measuring the forward and back bearings of each line and its length.

Field Notes: According to Form 9, p. 297. (*See Method of Procedure,* p. 298.)

Suggestion: If students work in parties of two each, one man should run the compass entirely around the polygon, and then the problem may be repeated, the other man running the instrument.

Questions: 1. What bearings are usually kept in a survey? p. 113. 2. In compass surveying why is it well to keep back-bearings also? p. 295, § 366 (7). 3. In compass surveying how are the relative positions of any two points determined? p. 293. 4. Give some objections to the use of the compass. p. 293. 5. What are some of the advantages? p. 293. 6. Give some practical suggestions for the use of the compass concerning the following points (see § 366, p. 294): Setting up; method of sighting; method of reading needle; protecting the pivot; avoiding sources of attraction; sluggish needle; duplicate readings. 7. Which sight vane should be next to the eye in sighting, and which end of the needle should always be read? p. 294. 8. Why will reading the bearings at both ends of a line reveal an error due to local attraction? 9. When it is impracticable, because of an obstruction, to take the bearing of a line directly, how may its bearing be found? 10. When is the declination arc used?

p. 295. 11. Give the general method of making a compass survey. p. 295. 12. How may details be located? p. 296. 13. If the bearings taken at the two ends of a line disagree, how may it be determined which is correct? p. 296, § 368 (a). 14. Illustrate how the effects of local attraction may be eliminated from the bearings of a number of connected lines. p. 296. 15. What are three chief sources of error in compass surveying? p. 298. 16. What are the limits of precision in compass surveying? p. 298. 17. Give the general method of rerunning old surveys. p. 298. 18. If in rerunning boundary lines two points on any one line are still preserved, what is the most direct method of ascertaining the change in magnetic declination which has taken place since the original survey? p. 299. 19. Why is it important to give on the map of a compass survey the date of the survey? p. 299. 20. What publication gives magnetic declinations at different places in the United States? p. 299.

GROUP S.

EXERCISES IN THE USE OF THE STADIA.

The exercises in this group afford practice in measuring horizontal distances and in determining elevations by the stadia method.

Exercise S–1.

To Test the Stadia Interval.

References: Pages 300–304.

Equipment: Transit equipped with stadia wires, stadia rod, steel tape, ax, and stakes.

Directions: Test the stadia interval for distances up to 400 feet according to the method explained in § 374, p. 302.

Field Notes: Give the number or the letter and the maker's name of the transit tested. Record the distance corresponding to each reading of the rod, and give the final value of the stadia interval as deduced from these distances.

Suggestions: It is well for several students in the party to test the stadia interval for the same transit, and the final value of this stadia interval should then be deduced from the observations taken by all of the students. If the stadia wires are adjustable and they are found out of adjustment, they should be reset as explained in § 375, p. 303. This may be done by the whole party working together under the supervision of the instructor.

Questions: 1. Define stadia, stadia wires, stadia rod. p. 300. 2. What are some of the different patterns of stadia rods in common use? pp. 573 and 574. 3. Give some suggestions for making a stadia rod. p. 574. 4. Can leveling rods be used as stadia rods? p. 300. 5. Define telemeter; tachymeter. p. 300. 6. Explain by means of a diagram the principle of the stadia. p. 301. 7. How may the constant C be determined by direct measurement? p. 302. 8. What is the average value of C for transits? for 18-inch wye-levels? *Remark*, p. 302. 9. Give the general method of testing stadia intervals. p. 302. 10. Explain the method of adjusting stadia wires. p. 303. 11. Is it essential that the two stadia wires should be equally distant from the horizontal cross-wire? What advantage is there in having them equally distant? p. 303. 12. Give some practical suggestions for adjusting stadia wires. p. 303. 13. Explain the method of graduating a rod for fixed stadia wires. p. 304. 14. Explain what is meant by interval factor, and how it may be ascertained in any given case. p. 304. 15. Which is to be preferred for accurate work — adjustable or fixed stadia wires? p. 304, *Practical Suggestions*. 16. What effect has refraction in determining the stadia interval (p. 313), and when should tests be made for very accurate work in graduating a rod? p. 304. 17. What are the advantages of using a standard rod and correcting readings by an interval factor? p. 304.

Exercise S-2.

To Measure Distances on Level Ground by the Stadia.

References: Page 304, § 377; p. 307, § 381 (a), (c), (d), (e).

Equipment: Transit with stadia wires, stadia rod, tape, ax, and stakes.

Directions: 1. Set up the transit over stake *A*. 2. Drive four stakes, *B*, *C*, *D*, and *E*, at distances from the transit varying from about 30 feet to 300 feet. 3. Using the stadia method only, find the distances *AB*, *AC*, *AD*, and *AE*. 4. Measure the above distances with the tape. 5. Repeat the exercises until a distance can be measured by the stadia with reasonable certainty.

Field Notes: 1. On the right-hand page give a description of the work; on the left-hand page, arrange in columns side by side the distances to each point as found by the stadia and as measured with the tape. 2. Give also your conclusions as to the limit of accuracy of the stadia method, basing your opinion upon the results obtained in this exercise.

Suggestions: Four students can work to advantage at each transit. While two are measuring by the stadia method, the other two can be measuring with the tape. Each student should take his turn in using the transit, but it is well to use a different set of stakes each time to avoid being prejudiced by the previous readings.

Questions: Give the general method of reading the stadia rod. p. 304. 2. What are some of the common mistakes? p. 305. 3. Give practical suggestions for the use of the stadia. p. 307. 4. How accurately can distances be measured with the stadia? p. 307 and p. 313, § 386 (a). 5. How long sights should be taken? p. 307.

Exercise S-3.

To Measure Horizontal Distances on Sloping Ground by the Stadia.

References: Pages 305–307.

Equipment: Transit with stadia wires, stadia rod, tape, ax, and stakes.

Directions: 1. Set up the transit over stake *A* driven where the ground is sloping. 2. Drive several stakes, *B*, *C*, *D*, *E*, at distances from the transit varying from 30 feet to 300 feet, and at points whose elevations vary considerably. 3. Read and record the inclined distance and the vertical angle to the rod held on each stake. 4. Reduce the inclined readings to horizontal distances as explained on p. 480, § 514. 5. Check the results by measuring horizontal distances with the tape.

Field Notes: Keep field notes on the left-hand page according to Form 11, p. 311, omitting the first two columns. On the right-hand page, arrange in systematic form all computations for reducing inclined distances.

Suggestions: 1. It is well to take some of the stakes above and some below the transit. Oftentimes the rod may be held on top of a fence, in a second or third story window, or at other points of varying elevations, instead of on stakes driven in the ground. 2. In multiplications for reducing inclined distances, use the abridged method. p. 481. It is well also to use reduction diagrams and slide rules.

Questions: 1. By means of a sketch, explain what two corrections are involved when the line of sight is inclined? p. 306. 2. Derive the formula for horizontal distance. p. 306. 3. In measuring horizontal distances with the stadia, when may vertical angles be ignored? Bottom of p. 307.

Exercise S-4.

To Obtain Vertical Distances or Elevations by the Stadia.

Reference: Page 308.

Equipment: Transit with stadia wires, stadia rod, tape, ax, and stakes.

Directions: 1. Set up the transit over the stake *A* driven in sloping ground. 2. Drive stakes *B*, *C*, *D*, and *E* at different elevations, and at distances from the transit varying from 50 to 300 feet. 3. Find the elevation of these stakes with respect to the stake under the transit by the method explained in § 382 (a), p. 308. 4. Repeat the work, finding the elevations of the same stakes with respect to a near-by bench-mark. 5. Find the elevation of each stake with respect to the stake under the transit, by the first method explained in § 341, p. 264, using the tape for measuring horizontal distances. Compare the results thus obtained with corresponding elevations obtained by the stadia (step 3, above).

Field Notes: 1. On the left-hand page keep the field notes according to Form 12, p. 311, omitting the second column. 2. On the right-hand page, keep in a systematic form all computations. 3. Show side by side the elevations as obtained from step 3 and step 5.

Suggestions: 1. See suggestions of the preceding problem. 2. When vertical distances or elevations are involved, *it is essential that the algebraic sign of the vertical angle should be carefully entered in the notes.*

Questions: 1. Explain the method of obtaining elevations of points with reference to a point under or near the instrument (p. 308, § 382 (a)); with reference to a bench-mark, some distance from the instrument. § 382 (b). 2. What is one of the first things to be given definitely in the notes? § 382 (c). 3. Upon what does the accuracy of elevations depend? § 382 (d). 4. If an error as large as 6′ is made in a vertical angle of about 14°, what would be the resulting error in elevation at a point 200 feet from the transit? p. 309. 5. If a vertical angle of about 14° is measured correctly, but the distance as obtained by the stadia is 1 foot greater than or 1 foot less than it should be, what is the resulting error in elevation? p. 309. 6. Is an error in measuring a vertical angle more important in large angles than in small angles, or vice versa? p. 309. 7. Is an error in measuring distances more important when the vertical angle is large, or when it is small? p. 309. 8. In ordinary work, how closely should distances and vertical angles be measured? p. 309. 9. When may vertical angles be read without the use of the vernier, and how closely should the corresponding distances be read? p. 309.

Exercise S-5.

Stadia Survey of a Polygon. (Azimuth Method.)

References: Pages 309–317.

Equipment: Transit with stadia wires, stadia rod, ax, and stakes.

Directions: 1. Drive four stakes to serve as four corners of an irregular polygon the sides of which vary in length from less than 100 feet to more than 200 feet. 2. Survey this polygon by the first azimuth method (p. 121), using the stadia for measuring all distances. Assume a magnetic north and south line as a reference meridian. Find the elevations of all stakes with reference to a bench-mark near the first station by the method explained on p. 308.

Field Notes: Use Form 10, p. 310.

Suggestions: Follow the practical suggestions given at the bottom of p. 309. Two men can work to advantage in each party in this exercise. If time permits, one should run the transit entirely round the polygon, the other acting as rodman. Then the exercise should be repeated, the two men interchanging positions and going round the polygon in the opposite direction. If desired, one of the other methods for running transit lines may be used instead of the azimuth method, or additional exercises may be given similar to this, involving the other methods of running transit lines.

Questions: 1. What methods are used for running transit lines in stadia surveys? p. 309. 2. What methods are used for locating details? p. 309. 3. Give some practical suggestions pertinent to stadia surveying. 4. Compare the forms of notes given on pp. 310 and 311. 5. Give some of the sources of error in stadia surveying. p. 312. 6. Explain why it is unwise during midday hours to take sights which require the line of sight to pass nearer than three feet to the ground. p. 313. 7. What should be the maximum probable error of sighting for distances up to 100 feet? p. 313. 8. What may be expected as a mean discrepancy between measurements made by the stadia and by the tape for distances of approximately 300 feet? p. 314. 9. What is the maximum error likely to occur in ordinary work in finding the elevation of a point from a vertical angle of about 10° and the length of sight of about 300 feet? p. 314. 10. Give the formula for determining the maximum allowable error in the sum of the lengths of the lines traversed. p. 315.

11. Give practical suggestions for stadia surveying concerning the following points: The constant; the stadia wires; method of sighting; reading the rod; length of sight; method of sighting when two stations are too far apart for a single sight; method followed when only a small portion of the rod can be seen; when vertical angles should be taken into account; checking distances between stations; checking distances of side shots; method of determining elevations; point of reference for elevations; the relations between the length of sights and the vertical angle; effect of an error in the adjustment of the telescope level-bubble avoiding needless refinements.

GROUP P.

EXERCISES IN THE USE OF THE PLANE TABLE.

The first five exercises in this group afford practice in the five fundamental methods used in plane-table surveying. The last exercise is one on the "three-point problem."

Exercise P–1.

Plane-table Survey of a Polygon.

(Method of Radiation.)

References: Pages 318–322; also pages 576, 577.

Equipment: Plane-table, and accessories (scale, hard pencil, pencil sharpener, drawing paper, triangles, fine needle, thumb tacks), steel tape, ax, and stakes.

Directions: Drive four stakes at random so that each will be the corner of a polygon, no side of which is less than 150 feet in length. 2. Set up the plane-table near the center of this polygon, and locate the corners by the method of radiation. p. 321. 3. Scale the lengths of the sides of the polygon and mark these lengths on the map; measure the lengths of the sides with the tape and mark these lengths on the map, thus affording a comparison and a check.

Suggestions: In this exercise adopt as large a scale as practicable and have the polygon come within the limits of the board.

Questions: 1. Give some of the requirements for the board of a plane-table. p. 576; for the alidade. p. 577. 2. What are some of the accessories? p. 577. 3. What is a traverse board? p. 577. 4. Give some of the tests for the plane-table. p. 577. 5. What is the peculiar characteristic of plane-table surveying? p. 318. 6. How are linear measurements made? p. 318. 7. For what kind of work is the plane-table especially useful? p. 318. 8. Give some of the advantages of the plane-table. p. 319. 9. Some of the disadvantages. p. 319. 10. Give some suggestions for setting up the plane-table. p. 319. 11. In most plane-table work is it essential to get a point on the map representing the position of the plane-table exactly over the corresponding point on the ground? p. 320. 12. Explain the method of radiation (p. 321). 13. What is the chief use of this method? p. 322.

Exercise P–2.

Plane-table Surveying of a Polygon.

(Method of Progression, or Traversing.)

Reference: Page 322.

Equipment: Same as for the preceding exercise.

Directions: 1. Repeat the preceding exercise, using the method of progression, or traversing. p. 322. 2. Check the work by measuring the diagonals of the polygon and comparing the results with the lengths obtained by scaling the map.

Suggestions: 1. Adopt a scale as large as the limits of the board will permit. 2. Throughout the work the *first* sight after orienting the table should be a check sight. These check sights are very important and should never be omitted.

Questions: 1. Explain the method of orienting the plane table. p. 322. 2. To which method of transit surveying does this method correspond? p. 323. 3. How should check sights be taken? p. 323. 4. Is it necessary to set up over the last station? p. 323. 5. If it is impracticable to set up over boundary lines, how would you proceed? p. 323. 6. How can a four-sided polygon be plotted in two set-ups, and how could the positions of the corners be checked? p. 323. 7. Can the method of traversing be used if some of the stations are inaccessible? p. 323. 8. For what kind of work is the method ordinarily used? p. 323. 9. In locating roads, banks of streams, etc., where should the stations be chosen? p. 323. 10. How may details of a plane-table survey be located? p. 323. 11. In a large topographic survey how are primary stations a valuable check on plane-table work? p. 323.

Exercise P–3.

Plane-table Survey of a Polygon.

(Method of Radio-Progression.)

Reference: Page 323.

Equipment: The same as for Exercise P-1.

Directions: Repeat Exercise P-1, using the method of radio-progression.

Questions: 1. Give some practical suggestions for this method. p. 324. 2. Comment on this method. p. 324.

Exercise P-4.

Plane-table Survey of a Polygon.

(Method of Intersection.)

Reference: Page 325.

Equipment: Same as for Exercise P-1.

Directions: Repeat Exercise P-1, using the method of intersection. p. 325. Although the four stations may be located with two set-ups, the work should be checked by setting up at a third station.

Questions: 1. Give practical suggestions concerning choice of stations; method of check lines. p. 325. 2. What are the advantages of this method, and in what kind of work is it especially useful? p. 326.

Exercise P-5.

Plane-table Survey of a Polygon.

(Method of Resection.)

Reference: Page 326.

Equipment: Same as for Exercise P-1.

Directions: Repeat Exercise P-1, using the method of resection. p. 326.

Questions: 1. What is the peculiar characteristic of this method? p. 326. 2. Give practical suggestions concerning the method of setting up; method of proceeding when there are more than four sides; method of check sights. 3. When is this method used? p. 327. 4. What are special cases of this method? p. 327.

Exercise P-6.

Discussion of Plane-table Surveying.

(Exercise for the Classroom.)

1. Compare the five methods used in plane-table surveying. p. 327. 2. Give practical suggestions concerning selection of paper; method of carrying paper; fastening paper to board; protecting paper in case of rain; connecting different sheets when two or more are used. p. 327. 3. Give practical sug-

gestions for manipulation of the plane-table, including, turning it slowly; manipulating the alidade; disturbance of the board. p. 327. 4. Give practical suggestions for plotting, including, method of sharpening pencil; use of scale; drawing lines; locating several points on the same straight line; drawing lines close to a straight edge; keeping track of points and lines. p. 328. 5. Give general suggestions including use of colored glasses; rules for cleanliness; drawing a north and south meridian; the use of check sights. p. 328. 6. How are vertical angles measured, and in what kind of work are they most used? p. 328. 7. Discuss practical questions relating to field work, including, three suggestions for choice of scale; choice of stations; method of locating details; limits of error; sources of error. p. 328.

Exercise P-7.

Plane-table Practice in the Three-point Problem.

Reference: Pages 329–334.

Equipment: Plane-table and accessories, three sight poles, piece of tracing cloth or tracing paper.

Directions: 1. Choose three points, A, B and C, visible from a station P to be occupied by a plane-table. The points a, b, and c should be plotted to represent three visible points. 2. Find the point p corresponding to P by the mechanical solution on p. 329. 3. Check the work by the graphic solution (Bessel's method). p. 330. 4. Repeat the exercise by the trial method (Coast Survey method). p. 332.

Suggestions: In this exercise time may be saved if the three given points are plotted before going into the field. For this reason the polygon used in one of the plane-table exercises already given may be chosen for this work, and three of its corners transferred to a clean sheet of paper by pricking through. When the fourth corner has been determined by the three-point method, the map of the whole polygon may be compared with maps made by other methods. Of course, it should be pointed out that when the three-point problem occurs in practice the three points themselves are usually long distances apart.

Questions: 1. Explain the mechanical solution of the three-point problem. p. 329. 2. Comment on this method. p. 330. 3. Explain Bessel's method. p. 330. 4. What is the chief objection to Bessel's method? p. 330. 5. How may this difficulty be overcome? p. 330. 6. On what principle is Bessel's solution based? p. 331. 7. Explain Llano's method. p. 331. 8. Explain the Coast Survey method. p. 332. 9. Give rules for guidance in Coast Survey method. p. 332. 10. Explain the Two-point Problem. p. 334.

GROUP To.

EXERCISES IN TOPOGRAPHIC SURVEYING.

The exercises in this group afford practice in practically all of the me for locating contours that are commonly used in topographic surveyin

Exercise To–1.

Running in a Contour.

References: Pages 337–341.

Equipment: Transit, leveling rod, ax, and stakes.

Directions: 1. Choose a place on a side hill where the surface is quite irregular; set up a transit and clamp the telescope so that the line of sight is horizontal. 2. Using the transit as a level, backsight on some near-by bench-mark, thus obtaining the elevation of the line of sight. 3. Setting the target at the proper grade rod, find points at intervals of about 25 feet on a contour whose elevation is an even multiple of 5 feet, marking each point with a stake.

Suggestion: In this exercise the elevation of the contour is immaterial, the object being to set a row of stakes 200 or 300 feet long that will show to a student how a given contour winds in and out along the surface of the ground (see also *Suggestion*, p. 337).

Questions: 1. Define contour; contour interval. p. 337. 2. What are some of the customary contour intervals? p. 337. 3. How can the imagination be helped in tracing a contour with the eye? p. 337. 4. What is a topographic map? What is its advantage over an ordinary map? p. 337. 5. How would the surface of a perfect cone be represented by contours? p. 338. 6. Give some of the fundamental principles concerning the following points: Contour lines crossing; contour lines merging; contour lines near together or far apart; line of steepest slope at any point; difference between closed contour lines indicating a hill and similar lines indicating a depression; continuity of contour lines; contour lines in pairs; a single contour line between two higher or two lower lines; contour lines across a stream. p. 338. 7. Why cannot a contour line turn down stream? p. 338.

8. Define ridge line; valley line. p. 339. 9. Where do the sharpest bends or curves in a contour line occur? p. 339. 10. When the convex side of the curve is toward lower ground, does it indicate a ridge, or a valley? p. 339. 11. What two general methods are there of locating contours? p. 340. 12. Explain the modified method. p. 341. 13. In the modified method, what should be the size of square? p. 341. 14. Give a system of numbering the corners of squares. p. 341.

Exercise To-2.

Topographic Survey of a Small Area. (Direct Method of Running in Contours with a Spirit Level.)

References: Pages 348, § 411 (a); 339, § 401; 341–348.

Equipment: Transit, level, leveling rod, drawing-board mounted on a tripod with accessories for plotting, including protractor, scale, and triangles.

Directions: Choose a place where the surface of the ground is quite irregular, and make a topographic survey of a small tract a few hundred feet square by the method explained in the first illustration, p. 348, § 411 (a).

Suggestions: 1. Each member of the party should follow the method of procedure for his position, outlined on p. 349, and before the survey is completed each should have had practice in all of the different positions. Read also *Remark*, p. 348. 2. After each member of the party has had practice in plotting notes in the field, it may be well to continue the survey without plotting the notes, using the combination method for field notes explained on p. 346.

Questions: 1. Give the general method of procedure for the levelman. p. 349. 2. As a rule, is it better to carry the work of leveling from station to station as the work progresses, or first to run a line of levels establishing bench-marks, and then to start anew from each station in running in contours? p. 349. 3. Give the method of procedure for the rodman. p. 349. 4. Give the method of checking a grade rod. p. 349. 5. How close should the line of sight come to the center of the target? p. 349. 6. Give the method of procedure for the transit man. p. 349. 7. Give the method of orienting the transit. 8. Give the method of procedure for the azimuth method. p. 156. 9. Is it usually necessary to read the vernier for either vertical or horizontal angles? p. 349, p. 109, § 152 (d). 10. When may vertical angles be ignored? p. 307. 11. What distances should be read twice? p. 349. 12. What lines should be checked with a needle? p. 349. 13. Give the method of procedure for the draftsman. p. 349. 14. Give two methods of plotting azimuths. p. 349. 15. Give different methods of reducing inclined stadia readings. pp. 480–483. 16. Give a method of keeping track of points. p. 349.

Exercise To-3.

Topographic Survey of a Small Area.
(Contours Interpolated by Spirit Leveling.)

References: Page 340, § 402 (b); p. 350, § 411 (b).

Equipment: Same as for the preceding exercise.

Directions: Make a topographic survey of a small area as in the preceding exercise, but use the method explained in the second illustration on p. 350.

Suggestions: 1. See suggestions for preceding exercise. 2. It may be well to cover exactly the same ground as in the preceding exercise, and to compare the map obtained by interpolating contours with that obtained in the preceding exercise by running in contours.

Exercise To-4.

Topographic Survey of a Small Area.
(Contours Interpolated by Means of the Vertical Angle Method.)

Reference: Page 350, § 411 (c).

Equipment: Transit, stadia rod or leveling rod, drawing-board mounted on tripod with accessories for plotting, including protractor, scale, and triangles.

Directions: Make a topographic survey of a small area as in the preceding exercise, but use the vertical angle and stadia for determining elevations instead of the spirit level, following the method of procedure outlined in the third illustration, p. 350.

Suggestions: See suggestions for the preceding exercise.

Questions: 1. Give the method of procedure for the transitman. p. 350. 2. How can spirit leveling be used in connection with this method? p. 350. 3. Give the method of procedure for the rodman. p. 350. 4. Give the method of procedure for the computer. p. 350. 5. Explain the use of the abridged method of multiplication in reducing stadia readings. p. 481. 6. Give the method of procedure for the draftsman. p. 350. 7. Give precautions for keeping track of points. p. 350.

Exercise To–5.

Questions Pertaining to Topographic Surveying. (For Class-room Discussion.)

Questions: 1. Name the different kinds of work done in a topographic survey. p. 339. 2. What is meant by horizontal control? p. 339. 3. What is meant by vertical control? p. 339. 4. Is the work of horizontal control always carried on simultaneously with that of vertical control? p. 339. 5. Give the different methods of establishing points of horizontal control. p. 340. 6. Give the different methods of establishing points of vertical control. p. 340.

Questions Concerning Horizontal Control.

7. Method of establishing primary stations in an extensive survey? p. 341. 8. Method of establishing secondary stations? 9. Method of tying the survey to a reference meridian? p. 341. 10. Methods of locating details? p. 342. 11. General methods of locating contours? p. 342. 12. For angular measurements, is the azimuth or the direct angle method most used, and why? p. 342. 13. What three other methods of horizontal control are frequently used? p. 342. 14. What method is most useful for linear measurements in a topographic survey? p. 342. 15. What precautions should be taken when the azimuth method is used? p. 342. 16. What precaution should be taken in establishing sub-stations? p. 342. 17. As a rule, is it necessary to read the vernier in locating contour points? Give an illustration of the error involved in not reading the vernier. p. 343.

Questions Concerning Vertical Control.

18. Methods of determining elevations of primary stations? p. 343. 19. Methods of determining elevations of secondary stations? p. 343. 20. Methods of determining elevations of contour points? p. 343. 21. In reading vertical angles to contour points, is it necessary to read the vernier? Illustrate the error involved in not reading the vernier. p. 343.

General Questions of Field Work.

22. Give some considerations which govern the choice of stations for horizontal control: (a) for triangulation stations, p. 192, § 247; (b) for secondary stations, p. 149, § 216. 23. In general, from what stations are contours most easily controlled? p. 344. 24. What are some of the other places where stations should be located? p. 344. 25. Give some suggestions for choosing stations for vertical control. p. 344. 26. Give suggestions for choosing controlling points of contours. p. 344. 27. Give additional suggestions for choosing controlling points for contours when the method of interpolation is used. p. 344. 28. What considerations govern the choice of contour intervals? 29. Give some of the considerations which govern the choice of methods and of instruments. p. 345. 30. Give some of the common combinations of instruments and methods. p. 346.

Questions Concerning Field Notes.

31. Give two general methods of keeping field notes in topographic surveying. p. 346. 32. Explain the combination method of keeping field notes. p. 346. 33. Explain the method of plotting notes in the field. p. 347. 34. Give some suggestions for sketching topography. p. 347. 35. Give some practical suggestions for field notes concerning the following points (347): special form of note book; common mistake in recording; uses of drawing-board and protractor; keeping track of the points; effect of moisture on paper; choice of scale.

GROUP M.

EXERCISES IN DETERMINING A TRUE MERIDIAN.

The exercises in this group afford practice in the determination of a true meridian both by observations on Polaris and by observations on the sun.

Exercise M-1.

Determination of a Meridian by Observations on Polaris at Elongation.

Reference: Chapter XXVIII, p. 354.

Equipment: Transit, lanterns, ax, stakes.

Directions: 1. Before the night of the observation, look up the time of elongation of Polaris. 2. Set up over a stake and proceed as explained in § 414, p. 356.

Field Notes: Keep a complete record of the work done, including a sketch showing the position of all stations or stakes.

Suggestions: It is well to conduct this exercise in connection with some regular survey. In that case, on some day previous to the night of observation, set a number of stakes, one for each party, on one of the main transit lines of the survey. The stakes should be at least twenty feet apart and in such a place that when the telescope is depressed after sighting at Polaris, a clear sight may be had from each stake for at least 300 feet. If this is done the true azimuth or the true bearing of the transit line may be computed the day following the observation by measuring the angle between each line established at the time of the observation and the transit line itself. (See sketch, p. 390.) The results thus obtained by different parties may then be compared.

Adjustments of the transit should be tested previous to the observation. It is well, however, to follow the modified method explained in § 414 (a), p. 357, thus eliminating error due to adjustment. Each party should be able to take several pairs of observations, checking those which are taken more than 10 minutes before or after elongation by the approximate formula on p. 359.

Questions concerning Polaris: 1. Is Polaris exactly at the north pole? p. 354. 2. If any star were at the pole how would a true meridian be determined? p. 354. 3. Why is Polaris chosen for observations? p. 354. 4. Describe a simple way of finding Polaris. p. 355. 5. To what constellation does Polaris belong? p. 355. 6. Define upper culmination and lower culmination. p. 355. 7. Define eastern elongation and western elongation. p. 355.

8. What is the sidereal day? p. 355. 9. If Polaris reaches its eastern elongation (or any other point in its orbit) at 7.45 P.M. on one evening, at what time will it reach the same point on the next evening? p. 355. 10. Define polar distance. What is its approximate value and approximate rate of change per year? p. 355. 11. If an observer at the equator points the telescope of his transit at Polaris when at its eastern elongation, how far will the line of sight be east of the true north? p. 355. 12. Explain why as the observer moves north from the equator the angle between a line of sight to Polaris at elongation and the true meridian grows larger. p. 355. 13. Explain the difference between azimuth and polar distance. p. 355. 14. How can one tell at what vertical angle to set the telescope in order to bring Polaris into the field? p. 356. 15. When Polaris is at its upper or lower culmination, how can the meridian be obtained? p. 356. 16. What is an approximate method of determining when Polaris reaches its culmination? p. 356. 17. When Polaris is between elongation and culmination, how can its azimuth be determined?

Questions concerning the methods of observing Polaris: 18. Name three methods of observing Polaris. p. 356. 19. Give in order the steps which must be taken in observing Polaris at elongation. p. 356. 20. What two objections are there to taking only one observation of Polaris at elongation? p. 357. 21. Explain a modified method by which these objections may be overcome. p.357. 22. Explain how to calculate the time of elongation. p. 357. 23. Why is it necessary that the transit should be in adjustment and that special pains should be taken in leveling up? p. 357. 24. What is a common way of bringing Polaris into the field of the telescope? p. 357. 25. Give practical suggestions for focusing; for illuminating cross-hairs. p. 357. 26. Describe the movement of Polaris in respect to cross-hairs as the star approaches elongation. p. 357. 27. What precaution should be taken after sighting on a star before depressing the telescope? p. 358. 28. Give practical suggestions for setting a stake and establishing the point after depressing the telescope. p. 358. 29. Explain the use of the approximate formula for checking observations. p. 358.

Questions concerning other methods of observing Polaris: 30. Explain the method of observing at culmination. p. 358. 31. Explain the method of observing Polaris at any time. p. 358. 32. What are the advantages of observing Polaris at elongation?

p. 358. 33. What is the largest permissible error if this method is used? p. 358. 34. What are the advantages and disadvantages of the method at culmination; at any time? p. 358. 35. Explain how a true meridian may be determined roughly by means of a plumb-line. p. 358. 36. What error may be expected in this method? p. 358. 37. Explain the method of determining magnetic declination. p. 358. 38. Give practical suggestions concerning the declination arc; overcoming a lack of sensitiveness of the needle; determining the declination without staking out a north and south line.

Exercise M-2.

Determination of a Meridian by a Single Observation on the Sun.

References: Appendix, pp. 620–627.

Equipment: Transit, stakes, ax.

Directions: Set up at one end of a line the bearing of which is to be determined, and follow the directions given in Art. 603, pp. 624 and 625.

Field Notes: For form see Art. 603 (d), p. 627.

Suggestions: (Read also the practical suggestions on p. 625, noting particularly *suggestion* (3) as to leveling up, also *suggestion* (15), p. 88.) The transit should be in perfect adjustment; this is convenient but not altogether necessary if method of procedure is followed as outlined. Several sets of observations should be taken by each party, each set giving a different solar triangle to solve. Preliminary practice in pointing the telescope at the sun will be necessary; reduce the shadow of the telescope (thrown on a piece of paper) to a small circle, when the sun may be observed through the telescope, or its image seen as explained in the "practical suggestions," p. 625. The sun may be also approximately found by turning back the colored glass of the prismatic eyepiece (in transits so furnished) and revolving the telescope about each axis until a decided glare is refracted to the eye, which must be held some distance away. Be careful not to use either stadia hair by mistake. Be certain that the image of the sun seen through the prismatic eyepiece is the *true* image; a false image much smaller is sometimes visible in some transits. What causes it? Check the transit work as to horizontal angles at the close of each set of observations by turning back to the original sight.

Questions concerning the sun and its image: 1. What is the sun's apparent *diameter* July 1? Jan. 1? What causes this variation? p. 625. 2. Does this apparent diameter vary with the sun's altitude? 3. What is the refraction correction for bodies on the horizon? bodies at an altitude of 45°? bodies at the zenith, and why? p. 624. 4. Is the refraction correction additive or subtractive as applied to an observed altitude, and why? p. 623.

5. What determines the amount of this correction other than a body's altitude? p. 623. 6. Which appears to us larger, the sun or the moon?

Questions concerning field work: 7. What is the best time of day for observations by this method? p. 625. 8. Why invert the telescope before taking second observation? p. 625. 9. Why take the two observations within a few minutes? p. 625. 10. What are errors of eccentricity and how corrected? 11. How nearly should azimuths by this method be relied on? 12. What is the comparative accuracy of two observations made with equal care, one at 8 A.M. and one at 11? 13. How does the probable error of an azimuth obtained by a single observation on the sun compare with that of one from Polaris at elongation? 14. Give the method of procedure used when the transit has a prismatic eyepiece; when it has not.

Questions Concerning the Solution of the Astronomical Triangle for Azimuth: 15. Define *declination.* p. 621. 16. Draw the astronomical triangle for the sun in July (declination 20° north), for an observation about 9 A.M. in Latitude 40° north. 17. Draw it for the sun in December (declination 20° south), for an observation about 3 P.M. in Latitude 25° north. 18. When is the declination of the sun zero? 19. When does it change most rapidly and how much is the change per hour? When most slowly and how much per hour? p. 622. 20. Neglecting refraction, how high is the sun in the sky at noon on March 22 in Latitude 40° north? 21. Is the *time* used in the solution of the triangle? What is the object of recording it? What would be the effect on the solution of an error of five minutes in the recorder's watch? 22. Explain how the term *azimuth* is understood by astronomers; by surveyors. 23. Compare this difference with the difference between the beginning of the astronomical day and of the civil day. 24. Is it necessary to know the longitude with accuracy? the latitude? 25. If you knew neither longitude, latitude nor time precisely, could you use this method and secure accurate results?

Exercise M-3.

Determination of a Meridian with Solar Attachment.

References: Appendix, pp. 627–632.

Equipment: Transit with solar attachment, stakes, ax.

Note: The solar attachment may be either Burt (604 a) or Saegmuller (604 b). In case the transit is provided with another form it may be necessary to consult the maker's catalogue for some suggestions as to its use. The principle of the graphic solution of the spherical triangle (see Fig. 600) is common to all.

Directions: Determine the bearing of the line in question by setting up at some convenient point thereon and following the method of procedure outlined on pp. 630–632.

Field Notes: These should include latitude of place, apparent declination of sun, standard time of observation and true bearing obtained.

Suggestions: Read carefully Arts. 600–602, and 604, including the suggestions on p. 631. Many of the suggestions in Exercise M-2 apply to this exercise as well. Be sure to level up by the method of *suggestion* (15), p. 89. The best time of day for determination of a meridian by this method is from 8.30 to 9.30 A.M. or 2.30 to 3.30 P.M., as the sun's apparent altitude when small is correspondingly uncertain, while for two hours before or after noon its path is so slightly inclined to the horizon as to make an accurate determination by this method difficult. The transit should be in perfect adjustment throughout, *including the solar attachment.* For adjustments of the various forms of solar attachments see the manufacturers' catalogues. Great care must be used throughout, in the use of this method, not to disturb or jar any part of the instrument after it has been set in position. A seemingly insignificant disturbance may render the result so inaccurate as to be useless. It is difficult to adjust the colored glass without deranging some part of the instrument, — avoid the necessity for this where possible. It is advisable not to depend on a single determination of bearing by this method, — if possible take a number at various times during the day. Note that the declination change from 8 A.M. to 4 P.M. on a single day is about 8 minutes of arc in March and September, but is nearly zero at the solstices. Various handbooks issued by instrument makers give, with sufficient accuracy for the purpose, the sun's declination daily throughout the year, together with the refraction corrections for various latitudes. For a representation of the solar spherical triangle which the solar attachment solves graphically, see Fig. 600.

Questions: 1. Does the refraction correction vary with the declination only? 2. When is it greatest and when least in Latitude 40° north? 3. On what does it directly depend? 4. Is it additive in north or south declination? p. 631. Why? 5. Must a similar correction be applied to the latitude? 6. Draw the astronomical triangle for Latitude 45° north, assuming the time to be 3 P.M. on Nov. 5 (declination 15¾° south). 7. What is the sun's apparent path for a single day, exactly? approximately? p. 628. 8. Define *declination, azimuth, hour circle.* Art. 600. 9. How does the local time enter into the problem? latitude? longitude? 10. Which must be known most accurately, and how large an error is permissible in each? 11. What will be the angle between the vertical planes of the two telescopes (Saegmuller) or of the solar attachment and the telescope (Burt) at the close of the operation? 12. How may it be measured in each case and what does it represent? 13. Article 604 (b) (2) mentions an index error in the vertical circle. How would this error affect the setting off of the declination? 14. Is the solar attachment applicable for use with a star? 15. What are the principal differences between the Burt and the Saegmuller solar attachments? p. 631. 16. Which would you prefer on a partly cloudy day? 17. Which is most accurate? 18. What are the advantages and disadvantages of the solar attachment method as compared with that of single solar altitudes? Compare their accuracy. 19. What should be the limit of error of the solar? How does either solar method compare with the Polaris method? 20. Plot the curve of declination of the sun for all or half the year. 21. What is the cause of the change? 22. Does it go through a complete cycle in a year of 365 days? 23. What other forms of solar attachments are in use beside the Burt and Saegmuller, and what are their distinctive features?

Note: If desired an exercise may be given in determining latitude by any one of the three methods explained on pages 632–633.

GROUP I.

A STUDY OF SURVEYING INSTRUMENTS.

The exercises in this group are intended for class-room discussions of the primary parts of surveying instruments and of each instrument as a whole. For the reasons given on page 537 it is well to postpone most of these discussions until after the student has become somewhat accustomed to the use of instruments. The discussion of any instrument will of course be of much greater value if one or more types of that instrument can be examined by the students during the discussion. Often it will be found desirable to take an instrument apart in order to show portions which are otherwise invisible.

Exercise I-1.

The Vernier, the Magnetic Needle and the Level Bubble.

References: Pages 538–545, §§ 565, 566 and 567.

Questions: 1. Who invented the vernier? p. 538. 2. Of what does a vernier consist? 3. What is meant by the " least count "? Illustrate by a sketch, or by constructing a rough vernier and scale of paper or cardboard. 4. What mark on a vernier usually serves as an indicator? p. 539. 5. What two steps are involved in any reading made by the aid of a vernier? 6. What is the sole use made of the vernier? *Remark,* p. 539. 7. Illustrate the method of reading a vernier either by a sketch or by means of a rough vernier such as that referred to in the second question. 8. What is the difference between a *direct* and a *retrograde* vernier? p. 540. Which form is the most common? When are retrograde verniers used and how are they read? 9. Give a general rule for determining the least count of a vernier; give a simpler rule. 10. By means of the figures on page 230 explain how to read a vernier on a leveling rod target, and point out the " danger points " where mistakes are likely to occur. 11. By means of the figures on pages 78 to 82 explain how to read verniers on transits and point out the " danger points." 12. Describe special forms of verniers such as a "folded" vernier. p. 83.

Questions on the Magnetic Needle: See *Questions* under *Exercise* Co-2, page 70 of this book.

Questions on the Level Bubble: See *Questions* under *Exercise L*-1 and *L*-5, pages 51 and 54 of this book.

Exercise I-2.

Theory of Lenses.

Reference: Page 545, § 568.

Questions: 1. What three forms of lenses are used most in telescopes? p. 545. Are they used singly or in combination? p. 546. 2. Of what shape is each surface of a double convex lens? 3. Define *optical center; principal focus; principal axis* and *focal length*, and illustrate by means of a sketch. 4. Upon what does the focal length depend? If the focal length does not depend upon the size of the lens, why is it usually greater for a large lens than for a small one? 5. Give the general proposition concerning a cone of rays emanating from a principal focus, and illustrate by a sketch. 6. How does this proposition apply to rays from the sun? p. 547. 7. Give the general proposition concerning a cone of rays emanating from any point beyond the principal focus. 8. Define *conjugate foci; secondary axis.* 9. From a principle of optics state the relation between the two distances from a lens to conjugate foci and the focal length of that lens. 10. Give the general proposition concerning a cone of rays emanating from any point at a distance from the lens *less* than the focal length. p. 548. 11. Define *virtual conjugate focus.* 12. How are images formed by a lens? 13. When is an image real and inverted and when virtual and erect? 14. What is the fundamental principle of the magnifying glass? 15 When is no image formed? 16. What is the fundamental principle upon which the object glass of a telescope is constructed? 17. How far from the lens of a camera should an object be placed to be photographed exact size? (Prove by equation (1), p. 547.) How far from the lens must the object be if the photograph is smaller than the object? Larger than the object? 18. To what is spherical aberration due? p. 549. To what is chromatic aberration due? 19. How can spherical aberration be corrected? How can chromatic aberration be corrected? 20. What is an *achromatic* lens?

Exercise I-3.

The Telescope.

Reference: Page 549, § 569.

Questions: 1. What is the function of the object glass of a telescope? p. 549. Of the eyepiece? 2. What is the difference between an inverting and a non-inverting telescope? Where does this difference lie? 3. Explain the construction of an eyepiece. How may it be centered? 4. Explain the construction of the objective. How is it moved in or out for focusing? 5. Explain the construction of the cross-hair ring, and method of attaching cross-hairs. 6. How may the reticle be drawn to one side or the other of the telescope tube? Why are the holes for the capstan screws left unthreaded? Why is it necessary to loosen one capstan screw before tightening the opposite screw? How may the whole ring be turned slightly? When is it necessary to turn it? 7. By means of a sketch, illustrate the theory of lenses applied to a non-erecting telescope, making clear what general proposition applies to the objective and what to the eyepiece. p. 550, § 569 (b). Explain the reason for the rule for focusing. 8. By means of a sketch, explain the difference between an erecting and a non-erecting eyepiece. 9. Compare these two types of eyepieces, giving the advantages and disadvantages of each. *Remark,* p. 553. 10. Name two special forms of telescopes. *Note,* p. 553. 11. What can you say regarding the terms " line of collimation " and " line of sight "? 12. Explain three defects which are inherent but should be corrected in telescopes. 13. Upon what does good " definition " depend? 14. What is " illumination " and upon what does it depend? What is the relation between illumination and magnifying power? 15. How does the " size of field " vary? 16. Upon what does " magnification " depend? Explain the relation between magnifying power and the size of the aperture; the relation between magnifying power and the level-bubble or the vernier. 17. Compare high power and low power telescopes, giving the advantages and disadvantages of each. p. 555. 18. For a given length of telescope why can the power be increased by using a non-erecting instead of an erecting eyepiece? 19. For a given power how is the height of standards affected by the use of a non-inverting eyepiece, and why is this an advantage? 20. How can a high and low power be obtained in the same telescope, and what are the advantages of such a telescope? *Remark*, p. 555. 21. What is "parallax," and how may it be eliminated? 22. Describe the tests for flatness of field. p. 556; for definition; for size of field; for size of aperture; for magnifying power. (These tests should be made by each student if circumstances permit.) 23. Summarize the principal points to be remembered in connection with the telescope as regards the objective, the eyepiece, the magnifying power, parallax, size of aperture, flatness of field and inherent defects.

Exercise I-4.

Chains and Tapes.

Reference: Page 559, § 570.

Questions: See page 6 of this book, questions 12, 14, 15 and 16, and page 9, questions 1, 4, 5 and 6. 1. Describe how a standard may be established for use in ordinary surveying. p. 562. 2. Describe a method for testing the length of a tape. p. 562.

Exercise I-5.

The Transit.

Reference: Page 563, § 571.

Questions: 1. What are the three principal parts of a transit? p. 563. 2. Explain how either the upper or lower plate can be revolved without turning the other, or how both can be revolved together. 3. Explain the construction of the inner and outer spindles. 4. Explain the workings of the different parts of a transit when a horizontal angle is measured. 5. What are the common methods of numbering the graduations on the limb? p. 67. 6. Explain how the various set-screws and tangent-screws work. p. 564. 7. If a transit is in perfect adjustment and is properly set up, why is it impossible to measure with it any angle which is not a horizontal or a vertical angle? *Remark*, p. 566. 8. What are some of the special attachments for the transit and their uses? 9. Name some of the most important requirements for transits as regards the spindles. p. 567; the limb graduations; opposite verniers; provision for reading vernier accurately; relation between magnifying power of telescope and least count of vernier; between magnifying power and sensitiveness of level-bubble; clamps and screws; tripod. 10. Name five additional requirements which may be met by adjustments. p. 568. 11. Give the test for eccentricity.

Exercise I-6.

The Level.

Reference: Page 569, § 572.

Questions: 1. What are the most essential qualities in telescopes for levels? p. 569. 2. What is the lower limit for magnifying power? 3. Why can the magnifying power of a telescope for a level be greater than that for a transit telescope and still be consistent with the sensitiveness of the level bubble? 4. Why is the upper limit for magnifying power placed at from 36 to 40 diameters on ordinary levels? 5. What are the ordinary limits for sensitiveness? 6. Upon what does stability depend? 7. What are the two distinguishing characteristics of a wye-level? What is the object of this construction? 8. Explain the construction of a dumpy level. What are its advantages and disadvantages? 9. Name some special forms of levels. 10. Describe some forms of home-made levels. *Note,* p. 571. 11. Describe some of the tests for the level not made in the ordinary adjustments.

Exercise I-7.

Leveling-rods and Stadia Rods.

References: Pages 571 to 575, §§ 573 and 574.

Questions on Leveling-Rods: 1. What is the difference between a *target* rod and a *self-reading* or *speaking* rod? p. 571. 2. Which is the better for ordinary leveling? 3. What is the difference between a *New York* rod and a *Philadelphia* rod? 4. What two common types of target are most used? p. 572. 5. What is the difference between a target with a scale and one with a vernier? pp. 228–230. 6. What is an *angle* target? How does it help in "plumbing" the rod? 7. Describe some special forms of leveling-rods. 8. Describe an *automatic* leveling-rod. 9. Describe a *plumbing-level.* p. 573. 10. What two tests should a good leveling-rod meet? p. 232.

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Questions on Stadia Rods: 11. Describe the target stadia rod. p. 573. Is it often used in practice? 12. Give some of the requirements which should be met by a good stadia rod. Compare the forms shown on page 574, giving the advantages and disadvantages of each. 13. Give some suggestions for making stadia rods. p. 574.

Exercise I-8.

The Compass, the Plane Table and the Sextant.

References: Page 575, § 575.

Questions on the Compass: See page 70 of this book, *Questions* 13 to 21.

Questions on the Plane Table: See page 79 of this book, *Questions* 1 to 4.

Questions on the Sextant: 1. What is the distinguishing characteristic of the sextant? p. 577. 2. What advantage has it over other instruments used for measuring angles? p. 578. 3. In what kinds of work is the sextant most used? 4. Explain the method of using the sextant in measuring horizontal angles. 5. Give some practical suggestions for the use of the sextant. p. 579. 6. How are vertical angles measured? 7. By means of a diagram, explain the theory of the sextant. p. 579.

Note: In connection with this exercise practice should be given in measuring both horizontal and vertical angles with the sextant. Problems similar to that on page 137, § 197, may be assigned by the instructor.

Exercise I-9.

The Care of Instruments.

Reference: Chapter XLVII, p. 607.

Questions: 1. What are some of the things to avoid in using instruments? p. 607. 2. What are some of the precautions which should be taken? p. 608. 3. Give suggestions for the care of steel tapes. p. 609. 4. Give suggestions for riveting a tape. 5. Give suggestions for soldering a broken tape. p. 610. 6. Give suggestions for emergency repairs to a tape by a splice. p. 611; by rough riveting. 7. What kind of lubricants are used for instruments? Which is the best? 8. How may screws and screw-holes be cleaned? p. 612. 9. How may graduated arcs be cleaned? 10. How may bubble tubes be replaced? p. 613. 11. Give suggestions for the care of lenses. p. 614; of focusing slides. 12. Explain in detail the method of replacing broken cross-hairs. p. 616. 13. How may dust be removed from cross-hairs? 14. Give suggestions for the care of tripods. 15. Give suggestions for the care of centers, spindles and centers.

Note: It is well to give the student an opportunity to make some of the repairs suggested by the above questions. Especially should he have an opportunity to replace cross-hairs and to mend a broken tape.

GROUP A.

ADJUSTMENTS.

The exercises in this group afford practice in the adjustments of all of the surveying instruments in common use. As pointed out in the introductory note to Chapter XLVI, page 581, the student should understand clearly the *reason* for each step of an adjustment, otherwise the exercises will be of little value.

GENERAL DIRECTIONS FOR EXERCISES A-1 TO A-7.

Each student should work at each adjustment until it is satisfactorily completed. It is suggested that in large classes men working on the same adjustment should be under the close supervision of an instructor, and that a general discussion of each adjustment of an instrument be held before beginning the next adjustment of that instrument. When there are a number of adjustments, as in the case of the transit, this breaking of the continuity of the work may give to students the false impression that the process is a long and difficult one. For this reason when all of the adjustments of an instrument have been completed by the students, it is well for the instructor to adjust the same instrument as rapidly as possible in the presence of the entire squad, emphasizing the logical order of the adjustments and showing how one may affect another.

It is presupposed that the discussions in Group I, pages 95–101, have been held before beginning adjustments, and that a thorough study of the different parts of instruments has been made. Of special importance are the questions on the construction of the telescope and the control of the cross-hair ring in *Exercise I*-3, p. 97 of this book; also questions on the construction of the transit and of the level, *Exercises I*-5 and *I*-6.

Exercise A-1.

Preliminary Discussion of Adjustments.

References: Pages 581 to 583.

Questions: 1. Why are certain of the parts of an instrument made adjustable? p. 581. 2. Can accurate work be done with an instrument out of adjustment? Can all errors be eliminated without adjusting the instrument? 3. How long may a good instrument stay in adjustment? How often should it be tested? 4. What are the two steps in each adjustment of any instrument? 5. What precaution should be taken to avoid wear on holes in capstan screws and nuts? p. 582. 6. Should each adjustment be perfected before beginning the next? What should be the final step? 7. In making any one adjustment how many times should the test and correction be repeated? How may time be saved? 8. What precautions may be taken to cause an instrument to "hold" its adjustments? 9. Give suggestions for working the capstan screws of a cross-hair ring. 10. Which cross-hair should be adjusted first. 11. Define *line of sight; line of collimation.* 12. If after adjustment the intersection of the cross-hairs appears to be out of the center of the field of vision what is generally the trouble? 13. How is parallax eliminated? p. 555. 14. Why is it well to set up an instrument in the shade during adjustments? 15. By means of a sketch, explain with care the *method of reversion.* 16. Show how this principle is involved in the adjustment of a home-made A-level explained in the note on page 571.

Note: Since the method of reversion is the basis of every adjustment, it should be discussed carefully and understood thoroughly before any attempt is made to adjust an instrument.

Exercise A-2.

Adjustments of the Transit.

Reference: Pages 581–591.

Equipment: Transit, steel tape, leveling-rod, sight pole, adjusting-pins, ax and stakes.

Directions: 1. Set up the transit, selecting if possible a level place where 300-ft. sights backward and forward in a straight line may be taken, and where the telescope can be directed to some well-defined high point. 2. Perform, in turn, each of the five principal adjustments of the transit by the methods explained on pages 581–591, paying particular attention to the reason for each step. (See also *General Directions* on page 102 of this book.)

General Questions on the Adjustment of a Transit: 1. What are the five principal lines of a transit? p. 584. (Illustrate with a transit.) 2. Is it as important that the plate levels should be in perfect adjustment when using the transit in level country as when using it in hilly country? 3. When is it important that the line of sight should move in a vertical plane (second and third adjustments)? 4. What kind of work requires that the telescope level should be in adjustment? 5. Why is it not essential in measuring vertical angles that the vertical circle should be in adjustment? *Caution*, p. 98.

Questions on the Adjustment of the Plate Levels: (To be discussed before the second adjustment is begun.) 6. What is the object of this adjustment? p. 584. 7. Describe the test. p. 585. 8. Explain the method of correction and state the principle involved. 9. When the final test is satisfactory how can *non*-parallelism in the axes of the inner and outer spindle be detected? *Suggestions*, p. 585. 10. Why is it best to adjust the plate levels with the lower plate clamped and the upper plate unclamped? 11. How can you tell in which direction to turn a capstan screw? p. 586.

Questions on the Adjustment of the Cross-hairs: (To be discussed before the third adjustment is begun.) 12. Why is the horizontal hair adjusted first? p. 582? (7). 13. What preliminary step may be taken? *Note*, p. 586. 14. What kind of work is affected by the adjustment of the horizontal hair? 15. What is the object in the adjustment of the horizontal hair? 16. The test? 17. Method of correction? 18. Is it necessary that the telescope should be horizontal during the adjustment of the horizontal hair? 19. Why should one point sighted at be near the transit, the other far away? 20. Give practical suggestions for the adjustment of the horizontal hair. p. 587. 21. When the horizontal hair is moved up or down is the vertical hair moved? *Note*, p. 550. 22. Suppose that in a telescope in which the eyepiece is erecting the horizontal hair should apparently be moved downward, which capstan screw is loosened and which tightened? p. 11. 23. What kind of work is affected by the adjustment of the vertical hair? p. 586. 24. What is the object in the adjustment of the vertical hair? p. 587. 25. The test? 26. The method of correction? 27. Why measure only one quarter of the distance between the two points? (Explain by diagram.) 28. Suppose the vertical hair is apparently to the right of the third point, which screw should be loosened and which tightened if the eyepiece is erecting? p. 589, (6). 29. Give some practical suggestions for adjusting the vertical cross-hair. 30. Suppose that after the cross-hairs have been adjusted the eyepiece is taken out or disturbed in any way, would this affect the adjustment of the hairs? p. 589.

Questions on the Adjustment of the Standards: 31. What kind of transit work is affected by this adjustment? p. 584. 32. What is the object of this adjustment? p. 589. 33. The test? 34. Method of correction? 35. Principle involved? 36. If the second point obtained in the test falls to the right of the first, which end of the supporting axis is the higher? 37. Give some practical suggestions for adjusting the standards. p. 591.

Questions on the Adjustment of the Telescope Level: 38. What is the object of this adjustment? p. 591. 39. When is it necessary to pay particular attention to this adjustment? p. 591. 40. What other instrument is always adjusted by the "peg method"? p. 601, I. 41. Explain by means of a diagram the test and the method of correction. (See also questions in connection with "peg" adjustment, p. 107 of this book.)

Questions on the Adjustment of the Vertical Circle: 42. What is the object of this adjustment? p. 591. 43. The test? 44. Method of correction?

Questions on Centering the Eyepiece and the Object-glass Slide: 45. If the intersection of the cross-hairs is obviously out of the center of the field of view does this necessarily indicate that the instrument is out of adjustment? p. 601. Does it affect the accuracy of the work? 46. Explain how to center the eyepiece. 47. How do the screws which move the centering ring differ in different instruments? p. 602. 48. Why does not the centering of the eyepiece affect other adjustments? 49. Why is no provision made for centering a non-erecting eyepiece? 50. What can you say regarding the centering of the object-glass slide? Explain the method.

Note: It is well to give the student an opportunity to actually center an eyepiece, either in connection with this exercise or during the adjustment of the level.

Exercise A-3.

Adjustments of the Wye-Level.

Reference: Pages 592–600.

Equipment: Level, one or preferably two leveling-rods, steel tape, adjusting-pins, ax and stakes.

Directions: 1. Set up the level in a shady place where a 300-ft. sight may be taken over approximately level ground. 2. Perform in turn each of the three principal adjustments of a wye-level by the methods explained on pages 592 to 600. (See also *General Directions* on page 102 of this book.) 3. All three adjustments having been completed apply the "peg method" test.

General Questions on the Adjustment of a Wye-Level: 1. What are the seven principal lines of a wye-leyel? p. 592. (Illustrate with a level.) 2. What is the object of the principal adjustments? 3. How is the line of sight made to coincide with the axis of the collars? 4. How is the axis of the bubble made parallel to the axis of the level-bar? p. 593.

Questions on the Adjustment of the Cross-hairs: (To be discussed before the second adjustment is begun.) 5. What is the object of this adjustment? 6. Describe the test. 7. Explain the method of correction and state the principle involved. 8. Is it necessary to level up for this adjustment? *Suggestions*, p. 594. 9. Give suggestions for working the capstan screws. 10. If there are two sets of capstan screws which set is used? 11. How may the horizontal hair be tested to ascertain if it is truly horizontal? If it is not, how is the correction made? 12. What defects in construction may be revealed by focusing on a point near the instrument and repeating the test?

Questions on the Adjustment of the Bubble Tube: (To be discussed before the third adjustment is begun.) 13. What is the object of the first step? p. 594. 14. Describe the test. 15. Explain the method of correction and the principle involved. 16. Is this first step an important one? *Practical suggestions*, p. 595. 17. If the tube is conical how will the bubble move during the test? Can this be remedied? 18. Why put on the sunshade? 19. What is the object of the second step in the adjustment of the bubble tube? p. 595. 20. Describe the test. 21. Explain the method of correction and the principle involved. 22. What precaution should be taken in turning the telescope end for end? *Practical suggestions*, p. 596. 23. Give suggestions for working capstan nuts. 24. Could this adjustment be made independent of the wyes? 25. Explain under what conditions this method of adjustment fails.

Questions on the Adjustment of the Wyes: 26. What is the object of this adjustment? 27. Describe the test. 28. Explain the method of correction and the principle involved. 29. Explain why undue importance is often attached to this adjustment. *Practical suggestions*, p. 597. 30. Why is it well to make alternate tests over different pairs of leveling screws? 31. Give suggestions for working capstan nuts. 32. When unable to perfect the adjustment where should one look for the trouble? 33. Why should the "peg-method" test be made? *Remark*, p. 597. When may this test be omitted?

Note: For questions on the "peg adjustment" see the next exercise. See p. 105 of this book for questions on centering the eyepiece.

Exercise A-4.

Adjustments of the Dumpy Level.

References: Pages 597 to 601.

Equipment: Dumpy level, two leveling-rods, steel tape, adjusting-pins, ax and stakes.

Directions: 1. Set up the level in a shady place where 200-ft. sights may be taken in opposite directions over approximately level ground. 2. Perform in turn each of the two adjustments, using the first "peg method" for the first adjustment. 3. When the adjustments have been completed apply the second "peg method." (See also *Practical suggestions*, p. 599.)

Questions on the "Peg Adjustment:" (To be discussed either just before or just after the first adjustment of the dumpy level.) 1. What is the object of this adjustment? p. 597. 2. By means of a figure, explain the test used in the first "peg method," and derive an expression for the error. p. 598. 3. What two methods of correction are there? Explain the first method; the second. 4. If the line of sight is inclined downward is the error added or subtracted? *Practical suggestions*, p. 599. 5. Give suggestions for choosing positions of pegs. 6. Why should more than one pair of readings be taken at the first set-up? 7. After the final adjustment of the target why should the rod be held at the stake nearer the level? 8. What defects of a wye-level may be disclosed by the "peg-method" test? How may they be remedied? 9. In applying the peg adjustment to a transit or a wye-level is it better to adjust the cross-hairs or the bubble tube? 10. By means of a figure, explain the test for the second "peg method." p. 600. 11. Explain the method of correction and the principle involved. 12. Explain a modified method of the peg adjustment. p. 600.

Questions on the Adjustments of the Dumpy Level. 13. What are the principal lines of the dumpy level? p. 600. 14. What is the object of the first adjustment? p. 601. 15. What is the test and correction? 16. As a rule is it better to adjust the cross-hairs or the bubble tube? Why? 17. Why do some engineers prefer a dumpy level with a non-adjustable bubble tube? 18. What is the object of the second adjustment? 19. What is the test and correction? 20. Explain how to adjust a dumpy level on which no provision has been made for raising or lowering the standards.

Note: See p. 105 of this book for questions on centering the eyepiece.

Exercise A-5.

Adjustments of the Compass.

Reference: Pages 602–603.

Equipment: Compass, adjusting-pins, plumb-bob and string, fine file, pliers or small brass wrench.

Directions: Make the tests for each of the four adjustments of the compass. For obvious reasons it will usually be impracticable in class work to make the corrections in the last three adjustments.

Questions: 1. What is the object in the adjustment of the levels? p. 602. Give the test and the method of correction. 2. What is the object in the adjustment of the sights? Explain the test and method of correction. 3. What is the object in the adjustment of the needle? p. 603. Explain the test and the method of correction. Give some practical suggestions for this adjustment. 4. What is the object in the adjustment of the pivot point? Explain the test and the method of correction. 5. Explain other tests for the compass. p. 576. 6. How may the needle be balanced? p. 612; how may it be remagnetized?

Exercise A-6.

Adjustments of the Plane Table.

Reference: Pages 603–604.

Equipment: Plane table and accessories, adjusting-pins, leveling-rod, steel tape, ax and stakes.

Directions: Make in turn each of the five adjustments of the plane table.

Questions: 1. Explain the adjustment of the levels. p. 604. 2. Explain the adjustment of the board. 3. Explain the adjustment of the telescope. 4. How may the line of sight and the edge of the ruler be made to lie either in the same vertical plane or in parallel planes? Is this essential? *Remark,* p. 604. 5. Explain the adjustment of the telescope level. 6. Explain the adjustment of the vertical circle. 7. Explain other tests for the plane table. p. 577.

Exercise A-7.

Adjustments of the Sextant.

Reference: Pages 604–606.

Equipment: Sextant, two blocks of wood or other objects of equal height, screw-driver.

Directions: Make in turn each of the four adjustments of the sextant.

Questions: 1. Explain the adjustment of the index-glass. p. 604. 2. Explain the adjustment of the horizon-glass. p. 605. Give some practical suggestions for this adjustment. 3. Explain the adjustment of the telescope. Give suggestions. 4. Explain the method of determining the index-error. p. 606. Give suggestions.

PART II.

EXERCISES IN OFFICE WORK.

Introductory.

The first seven groups of exercises in Part II are problems in office computation, while the remaining exercises are devoted to plotting and mapping. In each of these two kinds of work exercises are arranged in a progressive order, but it is intended that problems should be given, alternately, first in one and then in the other, so that the student may have practice both in computing and in plotting from the beginning of the course. There is a decided advantage in thus carrying on the two kinds of work side by side.

It is suggested that a separate-leaf notebook about 8 x 10½ inches be used for all computations. Each problem should be numbered to correspond to the number in this book, and dated. It is well at the top of each page to insert a heading which will show at a glance the nature of the problems on that page. *After problems have been checked they should be reinserted in the notebook, carefully arranged in order for future reference.* As problems in one exercise frequently involve work already done in a previous exercise, this arrangement is important.

Throughout the course, checking computations should be considered just as much a part of the work as making the computations in the first place. (See p. 362, § 420.) Much valuable training will be lost, moreover, if the student does not constantly strive to acquire the systematic methods of procedure which help so much in avoiding mistakes as well as in saving time. (See p. 363, § 421.)

All page references in Part II marked with an asterisk (as for example, p. 112 *) refer to pages in this book. All other page references are to pages in the author's text-book on *Plane Surveying*.

Since instructors may desire to insert additional problems, the numbering of problems is not continuous, intervals being left at the end of nearly every set.

GROUP G.

GENERAL METHODS OF COMPUTATION.

The aim in this group of exercises is to afford practice in the general methods of computation used in office work.

Exercise G–1.

Short Cuts in Arithmetical Work.

References: Pages 362 to 377.

Problems: 1. Explain how to multiply mentally 42 by 36, p. 364, § 424 (a). 2. Reduce 38 cubic yards to cubic feet mentally, p. 364. 3. Multiply 4821 by 819, p. 364, § 424 (b). 4. Divide 562981 by 72, p. 365, § 424 (c). 5. Multiply 589432 by 43416, carrying the result accurately to five places, p. 365, § 424 (d). 6. Multiply 589432 by 43416, using the usual method of long multiplication, and check the result by casting out nines, p. 366, § 424 (h). 7. Divide 58.264362 by 5.2314, carrying the result to four places (i.e., two decimal places), p. 366, § 424 (g). 8. Divide 58.264362 by 5.2314 by the ordinary method of long division and check the result by casting out nines, p. 367, § 424 (i). 9. Explain how to square mentally 44, 55, 7½, 7¼, p. 367, § 424 (j). 10. Find mentally the square root of 73 to two decimal places, p. 368, § 424 (k). 11. Extract the square root of 78620 by the approximate method, p. 368, § 424 (l). 12. Explain the method of checking by "Second Differences," p. 368. 13. Check the result of problems 6 above by excess of 11's, p. 369.

Questions: 1. Explain by illustrations different from those given in the book at least four general methods of checking computations, p. 362. 2. Name some of the approximate checks to be used in office work, p. 363. 3. Give some suggestions for saving time in office work, p. 364. 4. What is the main object in grouping like operations in addition to saving time? p. 364, § 423.

Exercise G-2.

Consistent Accuracy in Computations.

Reference: Page 369, § 425.

Note: The student should study § 425 with great care before working the problems. The importance of this exercise can hardly be overestimated. There is probably no one thing in office work so costly in time and money as the carrying of computations to an unnecessary and unwarranted number of figures. The student will be well repaid for all the study he may put upon this subject.

PROBLEMS.

14. A lot is 724.3 feet by 64.6 feet. Compute its area to as many places as the data will permit. (See illustration I, p. 373.)

15. Same as problem 14 except the lot is 724.35 feet by 64.62 feet. (See illustration II, p. 373.)

16. The radius of a circle is 2.167. Find the length of its circumference to as many places as the data will permit. (See illustration III, p. 373.)

17. The base of a triangle is given as 34.532 and the adjacent angle as 27° 27′. If the triangle is right-angled, what is the length of the perpendicular side? (See illustration IV, p. 373.)

18. Same as problem 17 except the angle to the nearest 10″ is 27° 27′. (See illustration V, p. 373.)

19. Same as problem 17 except that the base is given as 34.5 feet. (See illustration VI, p. 373.)

20. The length of a line is given by the lengths of four segments as follows: AB = 354 feet, BC = 3521 feet, CD = 21.69 feet, DE = 1.432 feet. What is the total length of the line AE expressed to as many places as the data warrant?

21. The circumference of a circle is given as 21.6 feet. Express its radius to as many places as the above length of the circumference will permit.

22. The perpendicular side of a right-angled triangle is given as 4368 feet and the base as 4800 feet. If the latter measurement was taken to the nearest 100 feet, express the tangent of the angle to as many places as the data will permit.

Questions: 1. It is stated that 25 men surveyed a line 25 miles long. What is the essential difference between the number 25 as applied to men and as applied to miles? 2. How many certain figures in the first "25"; in the second "25"? 3. Explain why consistent accuracy is not gained by carrying all numbers to the same number of decimal places, p. 370, § 425 (a). 4. What must one know in order to determine how many certain figures there are in numbers ending with ciphers, as, for example, the number 4000? p. 370, § 425 (b). 5. How many certain figures are contained in the number 0.0051, p. 370? 6. Illustrate the effect of uncertain figures in addition and multiplication, p. 371. 7. Give the general method of multiplication, p. 372, § 425 (g). 8. Give general suggestions for retaining and dropping figures in computations, p. 372.

Exercise G-3.

Trigonometric Relations Between the Sides of a Right-Angled Triangle.

Reference: Page 640.

Note: The trigonometric relations between the sides of a right-angled triangle are most easily remembered by keeping in mind the fact that to obtain a side of a triangle a trigonometric function is always multiplied by the *radius* of a circle. The purpose of this exercise is to review the trigonometric methods of solving right triangles.

Directions: 1. Draw carefully with drawing instruments a right-angled triangle ABC, whose base AB is 8.62 inches and whose perpendicular side BC is 6.24 inches (use the side of the scale divided to 50ths of an inch). 2. Draw the arc of a circle, beginning at B with A as a center (radius AB) corresponding to the first quadrant in trigonometry. 3. From this figure BC is evidently tangent to the circle, and the radius of the circle is AB; hence, AB multiplied by the tangent of CAB will give the length of BC; or, what is the same thing, BC divided by AB (the radius) gives the tangent of CAB. Likewise, AB multiplied by the secant of CAB will give the length of AC.

Problem 23: 1. Find the natural tangent of CAB in the above triangle to as many decimal places as the data will warrant. 2. Look up in the table of natural tangents the corresponding value of CAB. 3. Find the length of AC by multiplying AB by the secant of CAB, or, what is the same thing, by dividing AB by the cosine of CAB. 4. Check the length of AC by squaring AB and BC, using the table of squares, p. 683; also by scaling the length of AC on the drawing.

Directions: Draw the same triangle ABC, but with A as a center and AC as a radius draw an arc corresponding to the first quadrant. Functions will now be multiplied by AC (the radius) instead of AB, the triangle lying wholly within the quadrant.

$$AC \text{ sin. } CAB = BC$$
$$AC \text{ cos. } CAB = AB$$

Problem 24: Using the values of AC and of CAB found in the preceding problem, find the lengths of CB and AB by the above formulas to as many places as the data will warrant.

Note: The student will observe that when a triangle lies wholly within the quadrant (i.e., its hypothenuse is the radius of the arc) the sine and cosine are the functions used, whereas, if it extends outside of the quadrant (i.e., the base is the radius) the tangent, cotangent, secant and cosecant are used. When, as in many books, tables of secants are omitted, the reciprocal of the cosine may be used instead.

Exercise G–4.

Use of Logarithms.

References: Pages 374 to 376, pages 650 and 718.

Directions: 1. Before beginning this exercise go through the tables, p. 719 to p. 763, drawing indices or arrows at each of the four corners of every page as indicated on p. 375. 2. On a narrow strip of cardboard print two sets of headings to fit the tables as suggested in § 426 (4), p. 375.

Problem 25: 1. Given a triangle ABC right-angled at B. $AB = 24' \, 7\frac{1}{4}''$; $BC = 16' \, 4\frac{9}{32}''$. Reduce the given lengths to feet and decimals of a foot. (Use table on p. 650.) 2. Find the natural tangent of the angle CAB. 3. Find the corresponding value of the angle CAB. (Table XV.) 4. Find the logarithm of the natural tangent obtained above in (2). (Table XVII.) 5. Look up in the logarithmic tables (XVIII) the logarithmic tangent corresponding to the angle found in (3), and compare this logarithm with the logarithm found in (4).

Problem 26: Find the logarithms for the following quantities:

1. log. cos. 98° 12′
2. log. tan. 155° 13′
3. log. sin. 168° 12′
4. log. cot. 109° 43′
5. log. cos. 109° 12′ 20″
6. log. tan. 21° 33′ 44″
7. log. sin. 123° 14′ 32″
8. log. cot. 164° 12′ 18″

Problem 27: Find the angles corresponding to the following logarithms:*

1. log. $\overset{-}{\text{cos}}$. $A =$ 9.918147
2. log. $\overset{-}{\text{tan}}$. $B =$ 10.888449
3. log. $\overset{+}{\text{cot}}$. $C =$ 9.060016
4. log. $\overset{+}{\text{sin}}$. $D =$ 9.987186
5. log. $\overset{-}{\text{cos}}$. $E =$ 9.378321
6. log. $\overset{+}{\text{tan}}$. $F =$ 10.654632
7. log. $\overset{+}{\text{cot}}$. $G =$ 9.685417
8. log. $\overset{+}{\text{sin}}$. $H =$ 9.956666

Questions: 1. How may time be saved in logarithmic computations? p. 374, § 426 (1). 2. Give some suggestions for avoiding mistakes especially in interpolating, § 426 (2). What are some of the mistakes likely to be made when an angle is more than 90°? § 426 (3). 4. When several methods of computation may be used in finding angle or a side of a triangle, when would you use tangent and cotangents, and when sines and cosines? p. 376.

Logarithmic functions of angles near 0° *and* 90°. See p. 718.

Problem 28: Find by the method explained on p. 718 the logarithms of:

1. log. sin. 0° 43′ 45″
2. log. tan. 0° 38′ 15″
3. log. cot. 0° 59′ 14″
4. log. cos. 89° 02′ 25″

Find the angles corresponding to the following logarithms:

5. log. sin. $A =$ 8.174231
6. log. tan. $A =$ 8.235489
7. log. cot. $A =$ 11.984362
8. log. cos. $A =$ 8.060753

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* In problem 27 the angle should be expressed to the nearest second. Be careful to observe the algebraic sign given for each function.

GROUP B.

CALCULATION OF BEARINGS.

Exercise B-1.

Calculation of Bearings from Angles.

Reference: Before beginning this exercise students should study with great care the whole of Chapter XXX, beginning on page 378. First learn to convert angular distance into bearing and *vice versa*, as explained in § 432, especially in the note at the top of page 379. Work all the examples at the top of page 381 before trying to apply the method to a system of transit lines as explained in § 434.

Directions: Follow the form of computations given at the top of page 382 and apply by inspection the check of § 433 (e).

Problem 29: 1. Calculate the bearings of the transit lines *BC*, *CD*, and *DA*, p. 179, assuming *AB* to be N. 88° 15′ E.

30. Same as problem 29, assuming the bearing of *AB* to be N. 88° 15′ W. instead of N. 88° 15′ E.

Questions: 1. Give the algebraic signs of bearings and angles. 2. What is meant by angular distance? 3. Explain the general method of converting angular distance into bearing; of bearing into angular distance. 4. Give the general method of calculating bearings, p. 379. 5. Explain the reason which underlies the check of § 433 (e).

ADDITIONAL PROBLEMS.

Angles to the right. Calculate the bearings of the lines:

31. In the figure on p. 183, assuming *DA* to be N. 80° 30′ E.

32. In the figure *QRSTY*, p. 390, assuming *QR* to be N. 43° 10′ W.

33. In the figure *QRSTUVWNOPQ*, p. 390, assuming *QR* S. 36° 12′ W.

Angles to the left. Calculate the bearings of the lines:

34. In the figure on p. 183, using the same values as in problem 31 above, but going from D to C to B to A (counter-clockwise).

35. Same as problem 32, but go from Q to Y to T to S to R (counter-clockwise).

Angles to the right or to the left. Calculate the bearings of the lines: AB, BC, CD, DE, EF, FG, GH, HI, and IK. Clockwise = +; counter-clockwise = −. Use the values of the angles given below.

36. Line AB = N. 70° E.; $ABC = 199° +$; $CDB = 101° +$; $CDE = 71° -$; $DEF = 74° +$; $EFG = 98° -$; $FGH = 263° -$; $GHI = 82° +$; $HIK = 300° +$.

37. Same as problem 36 except assume the bearing of AB N. 70° W. instead of N. 70° E.

38. Same as problem 36 except start with the line EF, assuming its bearing to be N. 5° E.

39. Same as problem 38 except assume bearing of EF to be S. 5° E.

40. Line AB = S. 80° E.; $ABC = 100°\ 10' +$; $BCD = 265°\ 23' -$; $CDE = 86°\ 12' -$; $DEF = 243°\ 47' +$; $EFG = 168°\ 13' +$; $FGH = 58°\ 34' -$; $GHI = 38°\ 21' +$.

41. Same as problem 40 except start with EF whose bearing may be assumed EF = N. 70° E.

42. Same as problem 41 except assume bearing of EF = N. 70° W.

Deflection angles. Calculate bearings from the following deflection angles by the method referred to on p. 382, § 434 (b).

43. Line AB = N. 84° E.; B = 36° R., C = 43° L., D = 15° L., E = 52° R., F = 87° L., G = 21° R., H = 49° R., I = 17° L. Check the bearing of IJ by the method outlined at the bottom of p. 155.

44. Same as problem 43 except the bearing of AB is N. 84° W.

45. Same as problem 43 except bearing of AB is S. 8° W.

46. Same as problem 43 except bearing of AB is S. 12° E.

Exercise B-2.

Changing the Bearings of All Lines of a Traverse by a Given Amount.

Reference: Page 382, § 343 (c).

Problem 47: 1. Assuming the bearing of QR on p. 392 to be S. 44° 26′ E., change the bearings of RS, ST, TY, and YQ to correspond.

48. Assuming the bearing of QY on p. 392 to be N. 28° 16′ E., change the bearings of YW, WO, OP, and PQ to correspond.

ADDITIONAL PROBLEMS.

49. Assume CD on p. 386 to be a north and south line. Change the bearings of DA, AB, and BC to correspond.

50. Assume QR on p. 392 to be a north and south line. Change the bearings of RS, ST, TY, and YQ to correspond.

51. Assume the bearing of the line UV on p. 392 to be N. 0° E. Change the bearings of VW, WN, NO, OP, PQ, QR, RS, ST, and TU to correspond.

52. The bearings of four lines are given as follows: 1–2 = S. 5° 26′ W., 2–3 = S. 70° 39′ E., 3–4 = N. 47° 48′ E., 4–1 = S. 77° 33′ W. If the bearing of 3–4 is changed to N. 0° E., what are the corresponding bearings of the other three lines?

Exercise B-3.

Calculation of Angles from Bearings.

Reference: Page 382, § 435.

Problem 53: 1. $AB =$ N. 32° E., $BC =$ S. 8° W., $CD =$ N. 72° W., $DE =$ S. 20° W., $EF =$ S. 10° E., $FG =$ N. 63° E., $GH =$ S. 0° E., and $HI =$ S. 89° W. Find the angles measured clockwise at stations B, C, D, E, F, G, and H.

54. $AB =$ S. 70° W., $BC =$ S. 0° 21′ E., $CD =$ S. 86° 14′ E., $DE =$ S. 46° 43′ W., $EF =$ S. 90° W., $FG =$ N. 12° 37′ E., $GH =$ N. 44° 12′ W., and $HI =$ S. 41° 9′ W. Find the angles measured clockwise at B, C, D, E, F, G, and H.

ADDITIONAL PROBLEMS.

55. Calculate the interior angles of the polygon given in problem 76, p. 122,* and apply the closing check on p. 119, § 175.

56. Calculate the interior angles of the polygon given in problem 77, p. 122,* and apply the closing check on p. 119, § 175.

57. *AB* = S. 0° E., *BC* = S. 42° 18′ E., *CD* = N. 88° 14′ E., *DE* = N. 15° 47′ W., *EF* = N. 90° W., *FG* = S. 38° 58′ W., *GH* = N. 87° 17′ W., *HI* = N. 12° 11′ E. Find the angles measured clockwise at *B*, *C*, *D*, *E*, *F*, *G*, and *H*.

58. *AB* = N. 89° 12′ E., *BC* = N. 20° 19′ W., *CD* = S. 81° 54′ W., *DE* = N. 43° 29′ E., *EF* = S. 67° 21′ E., *FG* = S. 36° 57′ W., *GH* = N. 24° 33′ W., *HI* = N. 80° W. Find the angles measured clockwise at *B*, *C*, *D*, *E*, *F*, *G*, and *H*.

59. Calculate the *deflection* angles at *B*, *C*, *D*, *E*, *F*, *G*, and *H* from the following bearings: *AB* = N. 71° 12′ E., *BC* = S. 87° 23′ E., *CD* = N. 68° 54′ E., *DE* = S. 55° 42′ E., *EF* = N. 65° 24′ E., *FG* = N. 1° 22′ W., *GH* = N. 43° E., *HI* = N. 20° 18′ W. Indicate by the letters "R" and "L" which angles are to the right and which are to the left, and check results by the method explained at the bottom of page 155.

60. Calculate the deflection angles at *B*, *C*, *D*, *E*, *F*, *G*, and *H* from the following bearings: *AB* = S. 83° 09′ W., *BC* = N. 89° 03′ W., *CD* = *S*. 47° 12′ W., *DE* = S. 0° 0′ W., *EF* = S. 51° 14′ W., *FG* = S. 43° 42′ E., *GH* = S. 0° 09′ E., *HI* = S. 72° 53′ W., *IJ* = S. 20° 11′ W. Indicate by the letters "R" and "L" which angles are to the right and which are to the left, and check results by the method explained at the bottom of p. 155.

61. Calculate the deflection angles at stations: **8 + 50, 14 + 30, 19 + 21, 23 + 72, 28 + 91, 33 + 19,** and **40 + 10.** The bearings of the lines beginning with the line from **0** to **8 + 50** given in order are as follows: S. 80° 10′ E., N. 80° 24′ E., S. 71° 52′ E., S. 1° 11′ E., S. 43° 22′ E., S. 37° 18′ W., S. 86° 04′ W., S. 43° 12′ W. Indicate by the letters "R" and "L" which angles are to the right and which are to the left, and check results by the method explained at the bottom of p. 155.

62. Calculate the deflection angles at stations: **4 + 30, 8 + 95, 11 + 81, 15 + 20, 19 + 92, 24 + 03,** and **28 + 11.** The

bearings of the lines beginning with the line from 0 to 4
given in order are as follows: N. 3° 12′ W., N. 42° 19′ W.,
03′ E., N. 88° 58′ W., S. 63° 09′ W., N. 47° 18′ W., N. 0° 0′
N. 71° 21′ W. Indicate by the letters "R" and "L" w
angles are to the right and which are to the left, and c
results by the method explained at the bottom of p. 155.

GROUP L.

LATITUDES AND DEPARTURES.

Exercise L.

Calculation of Latitudes and Departures.

Reference: Chapter XXXI, pp. 384 to 394.

Directions: 1. In each problem make a rough sketch of the traverse lines, placing the bearing and length of each line on the sketch, as illustrated on p. 392. 2. Rule five columns with headings corresponding to those on p. 393. 3. In the first column put down the data, i.e. the bearing and length of each line, also the notation for the line, as illustrated in the first column on p. 393. 4. Look up all the logarithms, one right after the other, and enter them in the third and fourth columns; see p. 393. 5. Perform the necessary addition. 6. Look up the departures and latitudes corresponding to the logarithms found by addition, entering each departure and each latitude, as soon as found, in the second and fifth columns, respectively; see p. 393. 7. Tabulate the latitudes and departures as illustrated on p. 394. 8. If the traverse is a polygon and any large error is evident in the sums of the latitudes or the departures, apply the checks explained at the bottom of p. 389.

Note: The above method of procedure is practically the same as that given on p. 389. It will be observed that like operations are grouped (see p. 364, § 423), and the student will save time and avoid mistakes if he will follow closely the method of procedure indicated.

Problems: (To be assigned from the sixteen problems given below.)

Remark: The latitudes and departures computed in any problem of this exercise may be used in a subsequent exercise requiring the calculation of omitted measurements or the area of a polygon. Problems 75, 76 and 77 are used in this way repeatedly in succeeding exercises, while occasional use is made of Problems 71, 72, 73, 74 and 78. It will save time in the end, therefore, to assign as many of the problems given below as possible, even though it may seem that a disproportionate amount of time is being given to the mere calculation of latitudes and departures.

When the student has learned to compute latitudes and departures by means of logarithms, he may be given practice in solving some of the problems by the use of traverse tables. See p. 387, § 444 (b). He may also be given practice in the construction and use of a trigonometer. (See p. 388.)

PROBLEMS.

71. Calculate the latitudes and departures of the transit lines *ABCD*, p. 179.

72. Calculate the latitudes and departures of the transit lines *ABCD*, p. 183.

73. *AB* = N. 25° 16′ E., 150.0 ft.; *BC* = S. 59° 54′ E., 210.0 ft.; *CD* = S. 19° 28′ W., 285.5 ft.; *DA* = N. 32° 14′ W., 282.3 ft. Calculate and tabulate latitudes and departures.

74. *AB* = N. 26° 30′ E., 547.3 ft.; *BC* = S. 78° 18′ E., 504.8 ft.; *CD* = S. 9° 01′ E., 315.5 ft.; *DA* = S. 84° 30′ W., 791.6 ft. Calculate and tabulate latitudes and departures.

75. *AB* = S. 43° 16′ W., 206.6 ft.; *BC* = S. 12° 43′ E., 196.6 ft.; *CD* = S. 83° 45′ E., 530.9 ft.; *DE* = N. 3° 13′ W., 896.7 ft.; *EA* = S. 37° 26′ W., 623.7 ft. Calculate and tabulate latitudes and departures.

76. *AB* = N. 60° 15′ E., 432.6 ft.; *BC* = S. 70° 10′ E., 310.8 ft.; *CD* = S. 35° 30′ W., 290.5 ft.; *DE* = N. 65° 05′ W., 168.2 ft.; *EA* = N. 80° 47′ W., 351.3 ft. Calculate and tabulate latitudes and departures.

77. **1–2** = S. 73° 21′ E., 247.2 ft.; **2–3** = S. 40° 10′ E., 154.3 ft.; **3–4** = S. 26° 42′ W., 611.9 ft.; **4–5** = N. 14° 20′ W., 483.5 ft.; **5–1** = N. 12° 20′ E., 273.3 ft. Calculate and tabulate latitudes and departures.

78. Assume the bearing of the line *RS*, p. 392, to be S. 0° 0′ E. Change the bearings of *ST*, *TU*, *UV*, *VW*, *WN*, *NO*, *OP*, *PQ*, and *QR* to correspond. Calculate and tabulate the latitudes and departures of the perimeter of the figure, i.e., the polygon *RSTUVWNOPQ*.

79. Same as problem 78 except assume the line *UV* to be a north and south line, and change the bearings of the other nine lines to correspond.

80. **1–2** = N. 7° 54′ E., 483.4 ft.; **2–3** = N. 86° 46′ W., 380.6 ft.; **3–4** = S. 9° 38′ W., 225.9 ft.; **4–5** = S. 20° 10′ E., 241.9 ft.; **5–1** = S. 79° 18′ E., 272.7 ft. Calculate and tabulate latitudes and departures.

81. *AB* = N. 50° 55′ W., 449.3 ft.; *BC* = N. 1° 19′ W., 337.8 ft.; *CD* = N. 87° 38′ E., 264.9 ft.; *DE* = S. 38° 50′ E., 205.2 ft.; *EF* = S. 34° 50′ W., 120.5 ft.; *FA* = S. 4° 54′ E., 374.7 ft. Calculate and tabulate latitudes and departures.

82. $AB =$ N. 2° 05′ W., 183.5 ft.; $BC =$ N. 57° 40′ W., 273.3 ft.; $CD =$ S. 42° 25′ 30″ W., 639.4 ft.; $DE =$ S. 71° 18′ E., 598.4 ft.; $EF =$ S. 89° 37′ E., 340.0 ft.; $FA =$ N. 35° 14′ W., 412.2 ft. Calculate and tabulate latitudes and departures.

83. $AB =$ N. 56° 36′ W., 279.0 ft.; $BC =$ S. 44° 02′ W., 286.0 ft.; $CD =$ S. 25° 00′ W., 171.8 ft.; $DE =$ S. 40° 39′ W., 174.1 ft.; $EF =$ S. 71° 30′ E., 442.4 ft.; $FG =$ S. 87° 37′ E., 445.6 ft.; $GH =$ N. 41° 07′ W., 402.8 ft.; $HA =$ N. 5° 11′ E., 195.8 ft. Calculate and tabulate latitudes and departures.

Problems in calculating latitudes and departures from azimuth (reckoned clockwise from the north). Problems 84 and 85 are rough surveys and the error of closure should be corrected by the first method of balancing a survey explained on p. 395.

84. $AB =$ 32° 28′, 334 ft.; $BC =$ 20° 34′, 308 ft.; $CD =$ 239° 02′, 228 ft.; $DE =$ 219° 50′, 183 ft.; $EA =$ 175° 00′, 310 ft.; Calculate and tabulate latitudes and departures and balance the survey.

85. $AB =$ 18° 11′, 450 ft.; $BC =$ 355° 00′, 310 ft.; $CD =$ 322° 46′, 200 ft.; $DE =$ 221° 10′, 460 ft.; $EF =$ 152° 00′, 230 ft.; $FG =$ 123° 14′, 281 ft.; $GA =$ 189° 03′, 195 ft. Calculate and tabulate latitudes and departures and balance the survey.

86. Change all the bearings in problem   to azimuths, but retain the same lengths. Calculate and tabulate latitudes and departures. (The number of the problem to be inserted in the blank space will be assigned by the instructor from among the first thirteen problems given above.)

Note: An indefinite number of problems may be arranged by changing all the bearings in any one of the above problems by a given amount, as for example, by 30° + or 40° − and so on.

Questions:[*] 1. What is meant by the term latitude; departure? 2. Explain how each is found from the bearing and length of a line. 3. What are the algebraic signs for the different quadrants of bearings? 4. What is the departure of any north and south line, and the latitude of any east and west line? 5. Explain by means of a sketch how latitudes and departures may be used for determining the position of any station with respect to any other station in a system of transit lines, p. 385. 6. How may the error of closure be ascertained? p. 386. 7. For ordinary transit work what are the permissible errors of closure? p. 160. 8. Suppose that the permissible error for one angle is 30″ and that the total length of the perimeter of a sixteen-sided polygon is 5000 ft. What is the limit for the error of closure? p. 161. 9. Every line has two bearings. Which is used in computing latitudes and departures? p. 387. 10. Explain how to compute latitudes and departures from azimuths, p. 387. 11. Explain the use of traverse tables. 12. Explain the construction and use of a trigonometer. 13. Illustrate by sketch how the *true* bearings of traverse lines may be obtained by observation on Polaris, p. 389, § 445 (3). 14. How could true bearings be obtained from the magnetic bearings if the magnetic declination is known? p. 389, Remark. 15. So far as plotting is concerned, does it make any difference what value is taken for the bearing of the first line if the bearings of the other lines are calculated from that bearing? 16. When the sums of the latitudes or the sums of the departures are not equal within the limit of error, what three checks would you apply? (Bottom of p. 389.)

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[*] Many of the explanations involved in the answer to these questions should be illustrated by sketches at the black-board.

Questions on balancing survey: 1. What is meant by balancing survey? p. 395. 2. Is it usually necessary to balance a survey for purposes of plotting? 3. When is it necessary to balance a survey? 4. What two general methods are used for balancing a survey? p. 395. 5. Explain the first method. 6. What effect has the balancing of a survey on the original bearings and lengths? p. 396, Note. 7. How may the original bearings and lengths be corrected? 8. Explain the second method of balancing a survey (p. 396): (1) Measurements made under unfavorable conditions. (2) Linear measurements likely to be too long, which quantities should be decreased. (3) Effect of changes of long and short lines. (4) Effect of changes in north and south lines, and east and west lines. 9. Give the substance of Mr. Gould's discussion, p. 397.

GROUP T.

TRIANGULATION.

Exercise T-1.

Computations for Triangulations.

Reference: Page 399, § 488.

Directions: Find by calculation the lengths of the side of each triangle in a triangulation net, using the form shown on p. 400, § 448 (d). The student should prepare the above form for each triangle before looking up logarithms.

Problems: (To be assigned from the problems given below.)

PROBLEMS.

101. A triangulation net is composed of three triangles. The base line $BA = 1070.06$ ft. Adjusted values of the angles are given below.

Triangle ABC	Triangle ACD	Triangle ADE
$BAC = 82^\circ\ 16'\ 27''$	$CAD = 39^\circ\ 16'\ 11''$	$DAE = 63^\circ\ 38'\ 48''$
$ACB = 57^\circ\ 12'\ 03''$	$ADC = 100^\circ\ 42'\ 14''$	$AED = 49^\circ\ 27'\ 10''$
$ABC = 40^\circ\ 31'\ 30''$	$DCA = 40^\circ\ 01'\ 35''$	$EDA = 66^\circ\ 54'\ 02''$

102. A triangulation net is composed of three triangles. The base line $BA = 1421.36$ ft. Adjusted values of the angles are given below.

Triangle ABC	Triangle BCD	Triangle CDE
$ABC = 64^\circ\ 48'\ 41''$	$BCD = 60^\circ\ 21'\ 18''$	$CDE = 67^\circ\ 12'\ 42''$
$BAC = 61^\circ\ 21'\ 14''$	$CBD = 80^\circ\ 24'\ 28''$	$DCE = 63^\circ\ 16'\ 20''$
$ACB = 53^\circ\ 50'\ 05''$	$BDC = 39^\circ\ 14'\ 14''$	$CED = 49^\circ\ 30'\ 58''$

103. A triangulation net is composed of three triangles. The base line $AB = 2121.83$ ft. Adjusted values of the angles are given below.

Triangle ABC	Triangle ACE	Triangle CBD
$ABC = 55^\circ\ 10'\ 20''$	$ACE = 46^\circ\ 42'\ 20''$	$CBD = 82^\circ\ 51'\ 11''$
$BAC = 54^\circ\ 48'\ 15''$	$CAE = 88^\circ\ 51'\ 12''$	$BCD = 41^\circ\ 19'\ 04''$
$ACB = 70^\circ\ 01'\ 25''$	$AEC = 44^\circ\ 26'\ 28''$	$CDB = 55^\circ\ 49'\ 45''$

104. A triangulation net is composed of three triangles. The base line BD = 2421.16 ft. Adjusted values of the angles are given below.

Triangle BDC	Triangle BCA	Triangle DCE
BDC = 70° 00′ 45″	BCA = 49° 10′ 15″	DCE = 61° 24′ 10″
DBC = 56° 49′ 04″	CBA = 58° 36′ 30″	CDE = 60° 28′ 14″
BCD = 53° 10′ 11″	BAC = 72° 13′ 15″	DEC = 58° 07′ 36″

105. A triangulation net is composed of three triangles. The base line XY = 3121.42 ft. Adjusted values of the angles are given below.

Triangle XYW	Triangle XWU	Triangle YWV
XYW = 61° 22′ 44″	XWU = 59° 18′ 40″	YWV = 80° 09′ 10″
YXW = 58° 21′ 10″	WXU = 63° 12′ 10″	WYV = 40° 12′ 14″
XWY = 60° 16′ 06″	XUW = 57° 29′ 10″	YVW = 59° 38′ 36″

106. A triangulation net is composed of three triangles. The base line RS = 432.461 ft. Adjusted values of the angles are given below.

Triangle RST	Triangle RTU	Triangle STV
RST = 40° 21′ 40″	RTU = 38° 18′ 47″	STV = 94° 51′ 07″
SRT = 55° 39′ 15″	TRU = 93° 44′ 21″	TSV = 44° 06′ 41″
RTS = 83° 59′ 05″	RUT = 47° 56′ 52″	SVT = 41° 02′ 12″

107. A triangulation net is composed of three triangles. The base line 1–2 = 496.831 ft. Adjusted values of the angles are given below.

Triangle 1–2–3	Triangle 1–2–5	Triangle 2–3–4
1–2–3 = 37° 18′ 43″	1–2–5 = 43° 18′ 47″	2–3–4 = 61° 21′ 18″
2–1–3 = 36° 21′ 48″	2–1–5 = 41° 48′ 03″	3–2–4 = 58° 53′ 12″
1–3–2 = 106° 19′ 29″	1–5–2 = 94° 53′ 10″	2–4–3 = 59° 45′ 30″

108. A triangulation net is composed of three triangles. The base line 1–2 = 468.432 ft. Adjusted values of the angles are given below.

Triangle 1–2–3	Triangle 1–3–4	Triangle 3–4–5
1–2–3 = 92° 24′ 51″	1–3–4 = 41° 02′ 11″	3–4–5 = 40° 08′ 48″
2–1–3 = 41° 52′ 21″	3–1–4 = 44° 53′ 17″	4–3–5 = 41° 37′ 44″
1–3–2 = 45° 42′ 48″	1–4–3 = 94° 04′ 32″	3–5–4 = 98° 13′ 28″

Exercise T-2.

Miscellaneous Problems in Triangulation.

109. In Fig. 277 (e), p. 223, the length of the base-line *CD* is 423.738 ft. *ACD* = 109° 11′ 30″, *BCD* = 43° 42′ 12″, *ADC* = 33° 18′ 24″, *BDC* = 66° 28′ 20″. Compute the length of *AB*.

110. In Fig. 277 (f), p. 223, in order to find the distance *AC* a base line *AE* was laid off and its length found to be 231.763 ft. *CAE* = 36° 19′ 36″, *CEA* = 81° 54′ 10″. The vertical angle *CAB* = 21° 18′ 40″. The level line *AC* strikes the building four feet above a point on the ground. How high is the point *B* above the same point on the ground?

111. In the figure on p. 217 the length of base line No. 1 is 879.453, and that of base line No. 2 is 943.768 ft. *NHS* =38° 21′ 40″, *HNS* = 37° 10′ 5″, *HSN* = 104° 28′ 15″; *MSN* = 68° 30′ 42″, *SMN* = 62° 57′ 45″, *MNS* = 48° 31′ 33.″ Make all of the computations that are necessary for locating Piers *A* and *B*, assuming that the three spans are equal.

GROUP O.

OMITTED MEASUREMENTS.

Exercise O-1.

To Calculate the Bearing and Length of an Omitted Side of a Polygon.

Reference: Pages 400 to 402, Case I.

Directions: Follow the method of procedure given at the bottom of p. 401.

Problem: (To be assigned from the fourteen problems given below.)

PROBLEMS.

Note: In the first six problems the student may use latitudes and departures which he may have already calculated in the examples on p. 122.* In each problem there will be two solutions, the first from the lines of the polygon on one side of the missing line, the second from the lines of the polygon on the other side of the missing line. If there is no error of closure the results should be the same.

Find the length and bearing of the line

121. From *D* to *A* in Problem 75, p. 122.*
122. From *B* to *E* in Problem 76, p. 122.*
123. From **3** to **5** in Problem 77, p. 122.*
124. From *V* to *P* in Problem 78, p. 122.*
125. From *O* to *Q* in Problem 79, p. 122.*
126. From *E* to *H* in Problem 83, p. 123.*

127. Line	Bearing	Length	Latitude	Departure
MN	S. 47° 03′ W.	291.7	198.7	213.6
NO	N. 43° 55′ W	251.4	181.1	174.4
OP	N. 14° 57′ E.	346.4	334.1	89.2
PQ	N. 26° 12′ E.	250.7	224.9	110.7

Find the bearing and length of the line *QM*.

128. Line	Bearing	Length	Latitude	Departure
MN	N. 47° 48′ E.	1000.6 ft.	672.14	741.26
NO	N. 62° 38′ W.	573.29 ft.	263.53	509.13
OP	S. 76° 40′ W.	330.33 ft.	76.18	321.42
PQ	S. 5° 26′ W.	804.99 ft.	801.38	76.23

Find the bearing and length of the line *QM*.

129. *EA* = N. 65° 05′ E., 804.6 ft.; *AB* = S. 50° 20′ E., 370.5 ft.; *BC* = S. 25° 16′ W., 315.8 ft.; *CD* = S. 45° 31′ W., 291.6 ft. Find the bearing and length of *DE*.

130. *GC* = N. 84° 27′ W., 268.5 ft.; *CD* = N. 31° 53′ W., 337.2 ft.; *DE* = N. 30° 11′ E., 263.9 ft.; *EF* = S. 65° 10′ E., 310.6 ft. Find the bearing and length of *FG*.

131. **1–2** = N. 41° 48′ E., 212.4 ft.; **2–3** = S. 68° 19′ E., 411.3 ft.; **3–4** = S. 3° 51′ E., 394.7 ft.; **4–5** = S. 36° 10′ W., 381.6 ft. Find the bearing and length of **5–1**.

132. **1–2** = N. 46° 18′ W., 321.6 ft.; **2–3** = S. 48° 59′ W., 401.7 ft.; **3–4** = S. 0° 49′ E., 372.1 ft.; **4–5** = S. 8° 09′ E., 241.8 ft. Find the bearing and length of **5–1**.

133. In Problem 107, p. 126,* assume that the angles **3–2–4** and **2–4–3** are not known, but that all the other angles are as given in that problem. (*a*) Assume the bearing of **4–3** to be any value you please, and from this bearing compute the bearings of **3–1**, **1–5**, and **5–2** by the method of Chapter XXX, using angles **4–3–1**, **3–1–5**, and **1–5–2**. (*b*) Using these bearings and the lengths of **4–3**, **3–1**, **1–5**, and **5–2** (found by computation in Exercise T–1), compute the latitudes and departures of these four lines. (*c*) From these latitudes and departures compute the length and bearing of the line **2–4**. (*d*) Compare this length of **2–4** with the length found in the triangulation computation. (*e*) From the bearings of **4–3** and **4–2** find the angle **3–4–2** and compare its value with the value of **3–4–2** given in Problem 107, p. 126.*

134. A problem similar to Problem 133 made up from one of the triangulation problems on p. 125 or 126.*

Exercise O–2.

To Calculate the Omitted Bearing of One Side and the Omitted Length of Another Side of a Polygon.

Reference: Page 403, Case II.

Directions: Problems under Case II may be solved by two methods. In each of the problems given below follow that order of procedure on p. 403 which corresponds to the method called for in the problem. Notice the Remark, p. 403.

Problem: (To be assigned from the seventeen problems given below.)

PROBLEMS.

Note: In each of the first seven problems the student may use the latitudes and departures which he may have already calculated in the corresponding problem on p. 122,* except, of course, the latitude and departure of a side whose bearing or length is assumed to be omitted.

141. In Problem 75, p. 122,* assume the bearing of *DE* and the length of *EA* to be omitted. Calculate the omitted measurements by the first method of Case II, p. 403.

142. Same as Problem 141 except use the second method of Case II, p. 403.

143. In Problem 76, p. 122,* assume the bearing of *BC* and the length of *CD* to be omitted. Calculate the omitted measurements by the first method of Case II, p. 403.

144. Same as Problem 143 except use the second method of Case II, p. 403.

145. In Problem 77, p. 122,* assume the bearing of **3–4** and the length of **4–5** to be omitted. Calculate the omitted measurements by the first method of Case II, p. 403.

146. Same as Problem 145 except use the second method of Case II, p. 403.

147. A problem similar to the above problems made up from one of the problems on p. 122, 123, 125 or 126.*

148. *CD* = S. 47° 29′ W., 562.3 ft.; *DA* = N. 50° 15′ W., 380.4 ft.; *AB* = S. 65° 27′ E.; *BC* = 435.2 ft. Calculate the bearing of *BC* and the length of *AB*. Use the first method of Case II and check by the second method.

149. *AB* = N. 73° 58′ W., 125.5 ft.; *BC* = S. 8° 48′ E., 163.9 ft.; *CD* = 87.5 ft.; *DA* = N. 5° 40′ W. Calculate the bearing of *CD* and the length of *DA*. Use the first method of Case II and check by the second method.

150. *AB* = N. 40° 20′ E., 302.6 ft.; *BC* = N. 71° 15′ E., 282.2 ft.; *CD* = S. 50° 10′ E.; *DE* = S. 45° 25′ W., 510.6 ft.; *EA* = 466.3 ft. Calculate the bearing of *EA* and the length of *CD*, using the second method of Case II.

151. Same as Problem 150, using the first method of Case II.

152. *AB* = N. 40° 00′ E., 530.2 ft.; *BC* = S. 60° 20′ E., 421.6 ft.; *CD* = 527.4 ft.; *DE* = S. 65° 10′ W.; *EA* = N. 35° 10′ W., 578.6 ft. Calculate the bearing of *CD* and length of *DE*, using the first method of Case II.

153. Same as Problem 151, using the second method of Case II.

154. (In this problem the omitted measurements affect sides which are not adjacent.) *AB* = N. 46° 05′ E., 433.4 ft.; *BC* = S. 62° 50′ E., 183.6 ft.; *CD* = S. 27° 28′ E., 402.7 ft.; *DE* = S. 39° 48′ W.; *EF* = 52° 07′ W., 323.6 ft.; *FA* = 298.6 ft. Calculate the bearing of *FA* and the length of *DE*, using the second method of Case II.

155. Same as Problem 154, using first method of Case II.

156. *AB* = N. 32° 05′ E., 263.2 ft.; *BC* = N. 74° 18′ E., 234.4 ft.; *CD* = S. 12° 52′ W., 465.3 ft.; *DE* = 525.0 ft.; *EA* = S. 62° 27′ W. Calculate the bearing of *DE* and the length of *EA*, using the first method of Case II.

157. Same as Problem 156, using the second method of Case II.

Exercise O-3.

To Calculate the Omitted Lengths of Two Sides of a Polygon.

Reference: Page 404, Case III.

Directions: Problems under Case III may be solved by two methods. In each of the problems given below follow that order of procedure on p. 404, which corresponds to the method called for in the problem. Notice the " Remark " on p. 404.

Problem: (To be assigned from the fourteen problems given below.)

PROBLEMS.

Note: In each of the first seven problems the student may use the latitudes and departures which he may have already calculated in the corresponding problem on p.122,* except, of course, the latitude and departure of a side whose length is assumed to be omitted.

171. In Problem 75, p. 122,* assume the lengths of *BC* and *CD* to be omitted. Calculate the omitted measurements by the first method of Case III, p. 404.

172. Same as Problem 171 except use the second method of Case III, p. 404.

173. In Problem 76, p. 122,* assume the lengths of *BC* and *CD* to be omitted. Calculate the omitted measurements by the first method of Case III, p. 404.

174. Same as Problem 173 except use the second method of Case III, p. 404.

175. In Problem 77, p. 122,* assume the lengths of **2–3** and **4–5** to be omitted. Calculate the omitted measurements by the first method of Case III, p. 404.

176. Same as Problem 175 except use the second method of Case III, p. 404.

177. A problem similar to the above problems, made up from one of the problems on p. 122, 123, 125 or 126.*

178. *AB* = N. 68° 11′ W., 216.0 ft.; *BC* = S. 33° 35′ W., 167.0 ft.; *CD* = S. 32° 27′ E.; *DA* = N. 41° 59′ E. Calculate the lengths of *CD* and *DA*. Use the first method of Case III, and check by the second method.

179. *AB* = N. 16° 42′ E., 273.0 ft.; *BC* = S. 68° 23′ W., 388.5 ft.; *CD* = S. 10° 12′ E.; *DA* = N. 50° 46′ E. Calculate the lengths of *CD* and *DA*. Use the first method of Case III, and check by the second method.

180. *AB* = N. 36° 30′ E., 608.1 ft.; *BC* = S. 68° 18′ E., 560.9 ft.; *CD* = N. 0° 59′ E.; *DA* = S. 85° 30′ E. Calculate the lengths of *CD* and *DA*. Use the first method of Case III, and check by the second method.

181. *AB* = N. 10° 20′ W., 248.3 ft.; *BC* = N. 62° 18′ E., 324.6 ft.; *CD* = S. 74° 27′ E.; *DE* = S. 20° 22′ W.; *EA* = S. 68° 50′ W., 463.5 ft. Calculate the lengths of *CD* and *DE*, using the second method of Case III.

182. Same as Problem 181, using the first method of Case III.

183. (In this problem the omitted measurements affect sides which are not adjacent.) *AB* = S. 70° 05′ W., 437.9 ft.; *BC* = N. 15° 54′ W.; *CD* = N. 38° 16′ E., 217.6 ft.; *DE* = S. 10° 02′ W.; *EA* = S. 72° 25′ E., 366.4 ft. Calculate the lengths of *BC* and *DE*, using the second method of Case III.

184. Same as Problem 183, using the first method of Case III.

Exercise O-4.

To Calculate the Omitted Bearings of Two Sides of a Polygon.

Reference: Page 404, Case IV.

Directions: Follow the method of procedure of Case IV, p. 404. Notice the "Remark" under this case.

Problem: . (To be assigned from the nine problems given below.)

PROBLEMS.

Note: In each of the first four problems the student may use the latitudes and departures which he may have already calculated in the corresponding problems on p. 122,* except, of course, the latitude and departure of a side whose bearing is assumed to be omitted.

191. In Problem 75, p. 122,* assume the bearings of *BC* and *CD* to be omitted. Calculate the omitted measurements by the method of Case IV, p. 404.

192. In Problem 76, p. 122,* assume the bearing of *BC* and *CD* to be omitted. Calculate the omitted measurements by the method of Case IV, p. 404.

193. In Problem 77, p. 122,* assume the bearings of **2**–**3** and **3**–**4** to be omitted. Calculate the omitted measurements by the method of Case IV, p. 404.

194. A problem similar to the above problems, made up from one of the problems on p. 122, 123, 125 or 126.*

195. AB = N. 53° 56′ W., 296.4 ft.; BC = S. 21° 53′ W., 338.7 ft.; CD = 301.0 ft.; DA = 406.8 ft. Calculate the bearings of CD and DA.

196. BC = S. 41° 45′ W., 279.8 ft.; CD = N. 22° 14′ W., 286.4 ft.; DA = 194.2 ft.; AB = 254.5 ft. Calculate the bearings of AB and DA.

197. AB = 172.2 ft.; BC = 257.5 ft.; CD = S. 63° 37′ E., 298.8 ft.; DA = N. 13° 25′ W., 261.6 ft. Calculate the bearings of AB and BC.

198. (In this problem the omitted measurements affect sides which are not adjacent.) AB = N. 38° 40′ E., 340.5 ft.; BC = S. 67° 07′ E., 527.7 ft.; CD = 272.3 ft.; DE = S. 84° 44′ W. 669.6 ft.; EA = 265.2 ft. Calculate the bearings of CD and EA.

199. AB = Latitude 234.5 ft. N., departure 181.4 ft. E.; BC = Latitude 105.3 ft. N., departure 356.4 ft. E.; CD = Latitude 262.1 ft. S., departure 179.4 ft. E.; DE = 385.6 ft.; EA = 532.2 ft. Find the lengths of AB, BC, and CD, and the bearings of DE and EA.

Exercise O-5.

Calculation of Omitted Measurements.

Miscellaneous Problems.

211. In the figure on p. 405, let the distances Aa = 49.3 ft., Bb = 28.2 ft., Cc = 33.4 ft., and Dd = 24.4 ft. Angles Aab = 90° 23′, cdD = 102° 10′. Find the bearings and lengths of AB, BC, and CD. (See p. 406.)

212. In the figure on p. 177, assume the bearing of BC = N. 9° 15′ E. (1) From the notes on p. 176, calculate the bearings of AB, BC, CD, and DA, and also the bearing of the line from each station to the nearest corner. (2) By the method of Case I, p 401, calculate in order the bearings and lengths of the lines **1-2, 2-3, 3-4,** and **4-1.** (See illustration, p. 402, § 451 (c.))

213. Same as Problem 212 except use the method illustrated on p. 406.

214. By the method of Case I, p. 401, calculate the bearings and lengths of the three fence lines on p. 183.

215. Same as Problem 214 except use the method illustrated on p. 406.

Problems in Mine Surveying.

216. A vertical shaft of a mine is located at a point A and another at a point E. A point E' is at the bottom of the shaft directly under E. An underground traverse is run from E′ ending at a point A' directly under A. The bearing of $E'F'$ was *assumed* as S. 89° 05′ E. The other values are as follows: $E'F'$= 294.76 ft.; $F'G'$ = S. 89° 22′ E., 322.4 ft.; $G'H'$ = N. 15° 59′ E., 710 ft.; $H'I'$ = N. 15° 06′ W., 390.3 ft.; $I'A'$ = N. 63° 03′ W., 259.5 ft. Afterward a traverse was run on the surface of the ground as follows: AB = 636.43 ft.; ABC = 100° 49′, BC = 624.34 ft.; BCD = 180° 41′, CD = 218.66 ft.; CDE = 148° 23′, DE = 239.45 ft. All angles were measured clockwise. The true

bearing of AB was determined as S. 44° 18′ W. It is required to correct the assumed bearings of the underground survey so that they will be true bearings.

Note: As far as possible the logarithmic values on p. 393 may be used in the above example.

217. A traverse is run on the surface of the ground as follows: $AB =$ S. 41° 22′ E., 281.1 ft.; $ABC = 110° 45'$, $BC = 240.8$ ft.; $BCD = 124° 30'$, $CD = 339.7$ ft. Angles measured clockwise. At D a vertical shaft is sunk. From A a tunnel is run in a northeasterly direction at right angles to AB for 160 ft. to a point E' underground. It is then desired to run from E' to a point D' at the bottom of the shaft directly under D. What angle $AE'D'$ should be turned off clockwise?

If the elevation of A is 260.18 ft. and of D 428.16 ft. how deep will the shaft be from D to D' if the tunnel from A to E' is on a 5% grade and from E' to D' on a 6% grade?

218. A traverse is run on the surface of the ground from a point A to a point E as follows: $AB = 241.2$ ft.; $ABC = 129° 50'$; $BC = 204.3$ ft.; $BCD = 238° 46'$, $CD = 334.3$ ft.; $CDE = 125° 18'$, $DE = 380.2$ ft. The bearing of $DE =$ S. 54° 28′ E. At E there is a vertical shaft at the bottom of which is E' directly under E.

An underground traverse is run from E' to a point H' as follows: A line $M'E'$ is established directly below DE. $M'E'F' = DE'F' = 103° 12'$, $E'F' = 396.3$ ft.; $E'F'G' = 118° 45'$, $F'G' = 431.1$ ft.; $F'G'H' = 151° 13'$, $G'H' = 346.3$ ft. All angles measured clockwise. It is desired to sink a vertical shaft from a point H on the surface directly over H'. H is to be located by two intersecting lines passing through A and B respectively, and checked by a third line passing through C. Required the angles BAH, ABH and BCH and the lengths AH, BH and CH.

219. A boundary line of a mining claim is $AB =$ S. 13° 30′ W., length $= 350.8$ ft. A traverse is run on the surface from A to D as follows: (angles measured clockwise) $ABC = 91° 30'$, $BC = 226.4$ ft.; $BCD = 146° 05'$, $CD = 290.2$ ft. At D is a vertical shaft, D' at the bottom being directly under D. An underground traverse is run from D' to G' as follows: $CD'E' = 135° 10'$, $D'E' = 292.3$ ft.; $D'E'F' = 87° 20'$, $E'F' = 192.1$ ft.; $E'F'G' = 110° 6'$, $F'G' = 238.8'$. From G' it is desired to run due east to a point H' directly under the boundary line AB. Required the distance $G'H'$ and the distance AH, H being directly over H'.

Questions on the calculation of omitted measurements. 1. Why is the check given at the top of p. 400 better than the one on the preceding page? 2. How may triangulation be checked? (Remark 448 (c), p. 400.) 3. Can triangulation nets be solved by right-angled triangle methods? 4. Explain by a sketch the trigonometric relations between bearing, length, latitude, and departure. 5. What are "missing parts" in a polygon and how many parts may be omitted and still have the polygon determinate? 6. What are the four general cases in calculation of omitted measurements? p 401. 7. What is the principal difference between Case I and the other three cases? 8. Explain the method of Case I. 9. Explain the general method of Cases II, III, and IV. 10. In Cases II, III, and IV, show by figure that it is immaterial whether the two sides affected by omitted measurements are adjacent or not, p. 402, § 451 (d). 11. Why are two answers possible in Cases II and III? 12. Explain a second method used for Case II and Case III. 13. When is Case IV indeterminate? 14. Answer the question at the end of the chapter, p. 406.

GROUP A.

AREAS.

Exercise A-1.

The Use of the Planimeter.

Reference: Page 408, § 457.

Directions: Study carefully the directions of § 457 (c) and the practical suggestions on p. 409. This exercise is intended merely to teach the use of the planimeter. Additional practice in the use of the instrument should be obtained by checking the areas found in some of the other exercises by computations.

Problem: Draw accurately a circle of 4″ diameter, a square 3″ on a side, and a hexagon inscribed in a circle 5″ in diameter. Using the planimeter find the area of each of these three figures and check the results by computations.

Questions: 1. Give the general method of using the planimeter. 2. Does it make any difference whether the fixed point is placed within or without the boundary? 3. Give some practical suggestions, p. 409. 4. What tests should be made before using the planimeter? General direction, p. 410.

Exercise A-2.

To Compute Areas Directly from Field Measurements.

Reference: Page 410.

Directions: Compute the area of a polygon directly from measurements by the methods explained in § 458, giving the answer in square feet and in acres. Before beginning this exercise, make out a table in which 43560 is multiplied by each digit from 2 to 9. (See p. 377.) Do not carry computations farther than the data will warrant. (See p. 369, § 425.)

Problem: (To be assigned from the six problems given below.)

PROBLEMS.

231. The lengths of the sides of a four-sided polygon are as follows: $AB = 91.0$ ft., $BC = 83.9$ ft., $CD = 113.9$ ft., $DA = 91.1$ ft. The diagonal $AC = 130.2$ ft. Find the area of the polygon.

232. The lengths of the sides of a four-sided polygon are as follows: $AB = 75.3$ ft., $BC = 129.6$ ft., $CD = 97.0$ ft., $DA = 98.3$ ft. The diagonal $AC = 132.4$ ft. Find the area of the polygon.

233. The lengths of the sides of a four-sided polygon are as follows: $AB = 120.4$ ft., $BC = 83.6$ ft., $CD = 76.4$ ft., $DA = 94.7$ ft. From a point E near the center of the polygon distances are as follows: $EA = 75.0$ ft., $EB = 71.2$ ft., $EC = 54.7$ ft., $ED = 62.7$ ft. Find the area of the polygon.

234. The lengths of the sides of a four-sided polygon are as follows: $AB = 85.5$ ft., $BC = 98.0$ ft., $CD = 101.0$ ft., $DA = 99.0$ ft. From a point E near the center of the polygon distances are as follows: $EA = 54.9$ ft., $EB = 63.3$ ft., $EC = 69.0$ ft., $ED = 83.2$ ft. Find the area of the polygon.

235. Find the area of the polygon in Fig. 178, p. 120. See also p. 410, § 458 (c).

236. Find the area of the polygon *ABCD*, p. 179. See also p. 410, § 458 (c).

Exercise A-3.

Calculation of Areas from Offsets.

Reference: Pages 411 to 413.

Directions: Where offsets are at regular intervals use the "Trapezoidal Rule," p. 411. Where offsets are at irregular intervals use the first method, p. 412, § 459 (c), and check by the second method, arranging the work in determinate array as indicated in the illustration on p. 413.

Problem: (To be assigned from the four problems given below.)

PROBLEMS.

241. Offsets at 25-ft. intervals are as follows: **0+0**=20 ft., + **25**=14 ft., **0 + 50** = 18 ft., **0 + 75** = 6 ft., **1 + 0** = 12 ft., + **25**= 16 ft., **1 + 50** = 21 ft., **1+ 75** = 18 ft., **2 + 0** = 14 ft. ind the area in square feet.

242. Offsets at 50-ft. intervals are as follows: **0 + 0** = 18 ft., **0 + 50** = 23 ft., **1+ 0** = 36 ft., **1 + 50** = 30 ft., **2 + 0** = 16 ft., **2 + 50** = 28 ft., **3 + 0** = 37 ft., **3 + 50** = 41 ft., **4 + 0** = 21 ft. Find the area in square feet.

243. Offsets at irregular intervals are as follows: **0 + 0** = 12 ft., **0 + 20** = 18 ft., **0 + 60** = 24 ft., **0 + 82** = 15 ft., **0 + 95** =23 ft., **1 + 10** = 43 ft., **1 + 28** = 31 ft., **1 + 50** = 38 ft., **1+90** = 17 ft., **2 + 20** = 28 ft., **2 + 40** = 20 ft. Find the area in square feet.

244. Offsets at irregular intervals are as follows: **0 + 0** = 46 ft., **0 + 30** = 31 ft., **0 + 50** = 38 ft., **0 + 80** = 24 ft., **0 + 96**=12 ft., **1 + 16** = 27 ft., **1 + 30** = 22 ft., **1 + 70** = 14 ft., **2+10**= 28 ft., **2 + 40** = 36 ft., **2 + 70** = 25 ft., **3 + 20** = 8 ft. Find the area in square feet.

Exercise A-4.

Calculation of Areas from Latitudes and Double Longitudes.

Reference: Page 413.

Directions: Follow the method of procedure on p. 416, arranging the work as shown at the bottom of p. 417. It is well at first to compute the areas of figures whose latitudes and departures have been calculated in previous problems and thus avoid the work involved in the first step.

Problem: (To be assigned from the sixteen problems given below.)

PROBLEMS.

Note: In each of the first seven problems the student may use the latitudes and departures which he may have already calculated in the corresponding problem on p. 122.*

251. Calculate the area of the polygon in Problem 71, p. 122.*

252. Calculate the area of the polygon in Problem 72, p. 122.*

253. Calculate the area of the polygon in Problem 73, p. 122.*

254. Calculate the area of the polygon in Problem 74, p. 122.*

255. Calculate the area of the polygon in Problem 75, p. 122.*

256. Calculate the area of the polygon in Problem 76, p. 122.*

257. Calculate the area of the polygon in Problem 77, p. 122.*

258. From the latitudes and departures tabulated on p. 394, calculate the area of the figure on p. 392.

259. Calculate the area of the polygon in one of the problems (to be assigned) from 79 to 85 inclusive, pp. 122, 123.*

260. Calculate the area of one of the triangulation nets in Exercise T–1, p. 125,* by the method of latitudes and double longitudes, and check the result by the use of Formula 12, p. 408.

261. Calculate the area of the polygon in Problem 127, p. 128.*

262. Calculate the area of the polygon in Problem 128, p. 128.*

263. Calculate the area of the polygon in one of the problems of Exercise O–2, p. 129.*

264. Calculate the area of the polygon in one of the problems of Exercise O–3, p. 131.*

265. Making use of the results obtained in Problem 212, p. 134,* find the area in square feet of the polygon **1–2–3–4** on p. 177.

266. Making use of the results obtained in Problem 214, p. 134,* calculate the area of the land described on p. 183. Use the method of latitudes and double longitudes except for the portion between *CB* and the edge of the brook; this should be calculated from the offsets. (See also illustration at bottom of p. 419 for explanation of method.)

Questions: 1. What is usually taken as a reference meridian? p. 414. 2. How is the most westerly station determined? p. 472. 3. What is meant by the first and last courses? p. 414. 4. What is the longitude of a course and how is it obtained from the longitude of the preceding course? 5. Explain by means of a sketch the general method of calculating areas from latitudes and longitudes. 6. Why are double longitudes used and how is a double longitude of any course obtained from the longitude of the preceding course? p. 416. 7. Outline the general method of computing areas from latitudes and double longitudes, p. 416. 8. What are some of the sources of mistakes? p. 417. 9. By means of a sketch explain the method of computing areas from coördinates, p. 418. 10. Explain two general methods of computing irregular areas, p. 419. 11. Compare the two methods, p. 420.

Exercise A-5.

To Part Off a Required Area by a Line Having a Given Direction.

Reference: Case I, p. 422.

Directions: Follow the method of procedure of Case I, p. 422. Before beginning the exercise study carefully the illustration on p. 423.

Problem: . (To be assigned from the fourteen problems given below.)

PROBLEMS.

Note: In each of the first nine problems the student may use the area already calculated in the corresponding problem on p. 139 or p. 140.*

271. Divide the polygon in Problem 253, p. 139,* into two parts having equal areas by a line parallel to *CD*.

272. Divide the polygon in Problem 254, p. 140,* into two parts having equal areas by a line parallel to *DA*.

273. Divide the polygon in Problem 255, p. 140,* into two parts having equal areas by a line whose bearing is N. 30° W.

274. Divide the polygon in Problem 256, p. 140,* into two parts having equal areas by a line whose bearing is N. 60° W.

275. Divide the polygon in Problem 257, p. 140,* into two parts having equal areas by a line whose bearing is S. 60° E.

276. Divide the polygon in Problem 258, p. 140,* into two parts having equal areas by a line whose bearing is N. 75° E.

277. Same as Problem 276 except the bearing of the dividing line is N. 4° W.

278. Divide the polygon in Problem 261, p. 140,* into two parts one of which (bounded by the line *NO*) has an area double that of the other. The bearing of the dividing line is N. 45° W.

279. Divide the polygon in Problem 262, p. 140,* into two parts one of which (bounded by the line *MN*) has an area double that of the other. The dividing line is parallel to *MN*.

280. Find the position of a line parallel to *AB* which will divide the polygon *ABCDEF* into two equal parts. The latitudes and departures of the lines are as follows: *AB* = 400 ft. S., 800 ft. E.; *BC* = 300 ft. S., 500 ft. W.; *CD* = 600 ft. S., 400 ft. E.; *DE* = 200 ft. S., 1000 ft. W.; *EF* = 900 ft. N., 600 ft. W.; *FA* = 600 ft. N., 900 ft. *E*.

281. Find the position of a line parallel to *ED* which will divide the polygon *ABCDE* into two equal parts. The latitudes and departures of the lines are as follows: *EA* = 1500 ft. N., 300 ft. E.; *AB* = 400 ft. S., 800 ft. E.; *BC* = 300 ft. S., 500 ft. W.; *CD* = 600 ft. S., 400 ft. E.; *DE* = 200 ft. S., 1000 W.

282. Same as Problem 280 except that the area to be parted off is 10 acres, bounded on one side by *AB*.

283. Same as Problem 281 except that the area to be parted off is 8 acres, bounded on one side by *ED*.

284. Divide the land described on p. 179 into two equal parts by a line perpendicular to the street line.

Exercise A-6.

To Part Off a Required Area by a Line Starting from a Given Point.

Reference: Case II, p. 424.

Directions: Follow the method of procedure of Case II, p. 424. Before beginning the exercise study carefully the illustration on p. 426.

Problem: . (To be assigned from the fourteen problems given below.)

PROBLEMS.

Note: In each of the first nine problems the student may use the area already calculated in the corresponding problem on p. 139* or p. 140.*

291. Divide the polygon in Problem 253, p. 139,* into two parts having equal areas by a line starting from the point *A*.

292. Divide the polygon in Problem 254, p. 140,* into two parts having equal areas by a line starting from the point *B*.

293. Divide the polygon in Problem 255, p. 140,* into two parts having equal areas by a line starting from a point half way between *A* and *E*.

294. Divide the polygon in Problem 256, p. 140,* into two parts having equal areas by a line starting from a point half way between *B* and *C*.

295. Divide the polygon in Problem 257, p. 140,* into two parts having equal areas by a line starting from a point half way between **5** and **1**.

296. Divide the polygon in Problem 258, p. 140,* into two parts having equal areas by a line starting from the point *Q*.

297. Same as Problem 296 except the dividing line starts from the point *V* instead of *Q*.

298. Divide the polygon in Problem 261, p. 140,* into two parts one of which (bounded by the line *NO*) has an area double that of the other. The dividing line starts from *M*.

299. Divide the polygon in Problem 262, p. 140,* into two parts one of which (bounded by the line *MN*) has an area double that of the other. The dividing line starts from *Q*.

300. Same as Problem 280 of the preceding exercise, p. 142,* except that the dividing line starts from *A*, its direction being unknown.

301. Same as Problem 281 of the preceding exercise, p. 142,* except that the dividing line starts from *C*, its direction being unknown.

302. Same as Problem 282 of the preceding exercise, p. 142,* except that the dividing line starts from *C*, its direction being unknown.

303. Same as Problem 283 of the preceding exercise, p. 142,* except that the dividing line starts from a point on *EA* 500 ft. from *E*.

304. Divide the land described on p. 179 into two equal parts by a line starting from the middle of the western side.

GROUP E.

EARTHWORK CALCULATION.

Exercise E–1.

To Calculate Earthwork by the Method of Unit Areas.

(All cut or all fill.)

References: Pages 428 to 430, also page 287, § 362.

Directions: Before beginning the computation make a sketch as directed in the method of procedure at the bottom of p. 430. Follow this method of procedure closely, observing the practical suggestion on p. 431.

Problem: (To be assigned from the fourteen problems given below.)

PROBLEMS.

When the finished surface is level.

311. A rectangular plot is divided into 20-ft. squares and the corners are numbered according to the system shown in Fig. 402 (c), p. 341. The elevations at each corner in feet are as follows:

$A0$ = 28.1,
$A1$ = 26.2,
$A2$ = 24.3,
$A3$ = 27.1,
$A4$ = 22.4,
$A5$ = 21.9,
$A6$ = 26.3,
$B0$ = 25.2,
$B1$ = 23.2,
$B2$ = 25.9,
$B3$ = 22.2,
$B4$ = 20.1,
$B5$ = 19.4,
$B6$ = 24.3,
$C0$ = 23.1,
$C1$ = 20.1,
$C2$ = 21.8,
$C3$ = 19.4,
$C4$ = 17.6,
$C5$ = 16.1,
$C6$ = 18.4,
$D0$ = 20.2,
$D1$ = 17.4,
$D2$ = 16.9,
$D3$ = 15.4,
$D4$ = 14.5,
$D5$ = 13.2,
$D6$ = 15.4,
$E0$ = 23.8,
$E1$ = 21.2,
$E2$ = 18.0,
$E3$ = 17.8,
$E4$ = 18.9,
$E5$ = 21.1,
$E6$ = 22.3,
$F0$ = 24.0,
$F1$ = 25.1,
$F2$ = 26.4,
$F3$ = 26.9,
$F4$ = 25.3,
$F5$ = 23.8,
$F6$ = 27.1.

If the ground is graded to a level surface whose elevation is 12 ft., find the amount of earth to be removed. Answer in cubic yards.

312. Same as Problem 311 except it is required to find the amount of earth which must be filled in to bring the entire lot to a level surface whose elevation is 30 ft.

313. Same as Problem 311 except that the unit area is a 50-ft. square and the elevation of the level surface is 8.4 ft.

314. Same as Problem 312 except that the unit area is a 50-ft. square and the elevation of the level surface is 28.1 ft.

315. Same as Problem 311 except the unit area is a 50-ft. square and the elevation of the level surface is 9.9 ft.

316. Same as Problem 312 except the unit area is a 50-ft. square and the elevation of the level surface is 29.2 ft.

When the finished surface slopes in one direction only.

317. Assume the data given in Problem 311. The elevation of the finished surface at $A0$ and $F0$ is 12 ft., and this surface slopes downward at the rate of 1 ft. per 100 ft. to the line between $A6$ and $F6$ which is horizontal. Find the amount of earth to be removed.

318. Assume the data given in Problem 311. The elevation of the finished surface at $A6$ and $F6$ is 30 ft., and this surface slopes upward at the rate of 0.5 ft. per 100 ft. to the line between $A0$ and $F0$ which is horizontal. Find the amount of earth to be added.

319. Same as Problem 317 except the slope is 1.5 ft. per 100 ft.

320. Same as Problem 318 except the slope is 1.0 ft. per 100 ft.

When the finished surface slopes in two directions.

321. Assume the data given in Problem 311. The plane of the finished surface is determined by two lines, one from $A0$ to $A6$, the other from $A6$ to $F6$. The elevation of this surface at $A0$ is 13 ft.; at $A6$, 11.5 ft.; at $F6$, 12.5 ft. Find the amount of earth to be removed.

322. Same as Problem 321 except the elevation of the finished surface at $A0$ is 30 ft.; at $A6$, 31.2 ft.; at $F6$, 29.0 ft. Find the amount of earth to be added.

323. Same as Problem 321 except the unit area is a 50-ft. square and the elevation of the finished surface at $A0$ is 10 ft.; at $A6$, 11.8 ft.; and at $F6$, 12.3 ft.

324. Same as Problem 322 except the unit area is a 50-ft. square and the elevation of the finished surface at *A*0 is 28.1 ft.; at *A*6, 29.9 ft.; and at *F*6, 30.9 ft.

Questions: 1. What is meant by a 3 per cent grade or gradient? p. 428. 2. How are the elevations at different points corresponding to a given grade calculated? p. 428. 3. What is the cut or fill at any point, and the corresponding algebraic signs? p. 429. 4. What is a polyhedron; a truncated prism; a right-truncated prism? p. 429. 5. What is the volume of a truncated prism equal to? 6. Give the general method of calculating earthwork from unit areas, p. 429. 7. Explain the method of procedure when the finished surface slopes in one direction; when it slopes in two directions. 8. Explain the method of procedure when the outline of an area is not rectangular, p. 431. 9. Give suggestions: (a) For a systematic method of computation, p. 431; (b) as regards the size of a unit square, p. 432. 10. In very uneven ground how may the method of unit rectangles or squares be modified to obtain greater accuracy? p. 432.

Exercise E-2.

To Calculate Earthwork by the Method of Unit Areas.

(Irregular Boundaries.)

This exercise is the same as the preceding exercise except that the outline of the area to be graded is not rectangular, but irregular. The instructor should make up a problem similar to that indicated in Fig. 467 (g), p. 431, or Fig. 468, p. 432, establishing the elevations for the finished surface in such a way that it will lie entirely below or above the original surface, i.e., so that the grading will be all cut or all fill.

Exercise E-3.

To Estimate Cut and Fill by the Method of Unit Areas.

Reference: Page 432, § 468.

Directions: Before beginning the computation, make a sketch as directed in the method of procedure at the bottom of p. 430. Determine by interpolation the points where there is neither cut nor fill. (See p. 433.) Calculate separately the cut and the fill, each by the method of § 467 (e), p. 430. For the methods of interpolation see § 469, p. 433; also p. 497.

Problem: (To be assigned from the thirteen problems given below.)

PROBLEMS.

When the finished surface is level.

331. A rectangular plot is divided into 20-ft. squares and the corners are numbered according to the system shown in Fig. 402 (c), p. 341. The elevations at each corner in feet are as follows:

*A*0 = 42.4,
*A*1 = 41.3,
*A*2 = 42.1,
*A*3 = 43.2,
*A*4 = 39.6,
*A*5 = 38.7,
*A*6 = 36.3,
*B*0 = 43.1,
*B*1 = 44.0,
*B*2 = 42.8,
*B*3 = 41.6,
*B*4 = 39.9,
*B*5 = 39.2,
*B*6 = 37.1,
*C*0 = 44.2,
*C*1 = 45.6,
*C*2 = 43.9,
*C*3 = 42.1,
*C*4 = 41.8,
*C*5 = 39.9,
*C*6 = 36.0,
*D*0 = 41.6,
*D*1 = 40.9,
*D*2 = 41.0,
*D*3 = 41.4,
*D*4 = 40.3,
*D*5 = 39.1,
*D*6 = 36.9,
*E*0 = 42.6,
*E*1 = 41.4,
*E*2 = 38.7,
*E*3 = 36.3,
*E*4 = 37.2,
*E*5 = 36.1,
*E*6 = 35.0,
*F*0 = 43.2,
*F*1 = 42.1,
*F*2 = 37.8,
*F*3 = 35.4,
*F*4 = 34.6,
*F*5 = 33.2,
*F*6 = 31.7,
*G*0 = 45.8,
*G*1 = 43.4,
*G*2 = 41.2,
*G*3 = 39.7,
*G*4 = 37.4,
*G*5 = 31.0,
*G*6 = 30.0.

Calculate the cut and fill required to grade the plot to a level surface whose elevation is 40.0 ft. Answer in cubic yards.

332. Same as Problem 331 except the elevation of the level surface is 39.0 ft.

333. Same as Problem 331 except that the unit area is a 50-ft. square and the elevation of the level surface is 37.0 ft.

334. Same as Problem 331 except that the unit area is a 50-ft. square and the elevation of the level surface is 42.0 ft.

335. What should be the elevation of the level surface in Problem 331 in order to make cut and fill equal?

When the finished surface slopes in one direction only.

336. Assume the data given in Problem 331. The elevation of the finished surface at A0 is 40.0 ft.; at A6, 38.5 ft.; at G0, 40.0 ft.; and at G6, 38.5 ft. Calculate the cut and fill in grading to a plane surface determined by these four elevations.

337. Same as Problem 336 except the elevations are as follows: A0, 41.0 ft.; A6, 38.0 ft.; G0, 41.0 ft.; G6, 38.0 ft.

338. Same as Problem 336 except the unit area is a 50-ft. square and the elevations are as follows: A0, 39.0 ft.; A6, 37.5 ft.; G0, 39.0 ft.; G6, 37.5 ft.

339. Same as Problem 336 except the unit area is a 50-ft. square and the elevations are as follows: A0, 41.0 ft.; A6, 39.2 ft.; G0, 41.0 ft.; G6, 39.2 ft.

When the finished surface slopes in two directions.

340. Assume the data given in Problem 331. The plane of the finished surface is determined by two lines, one from A0 to A6, the other from A6 to G6. The elevation of this surface at A0 is 42.0 ft.; at A6, 40.2 ft.; at G6, 38.4 ft. Calculate the cut and fill.

341. Same as Problem 340 except the elevation of the finished surface at A0 is 41.8 ft.; at A6, 38.2 ft.; at G6, 39.4 ft.

342. Same as Problem 340 except the unit area is a 50-ft. square and the elevation of the finished surface at A0 is 40.2 ft.; at A6, 39.0 ft.; at G6, 37.2 ft.

343. Same as Problem 340 except the unit area is a 50-ft. square and the elevation of the finished surface at A0 is 39.0 ft.; at A6, 40.2 ft.; at G6, 38.4 ft.

Exercise E-4.

To Calculate Cut and Fill by the Method of Unit Areas.

(Irregular Boundaries.)

This exercise is the same as Exercise E-2, p. 146,* except that the finished surface is such that the calculations will be for both cut and fill, instead of for all cut, or for all fill.

Exercise E–5.

Calculation of Earthwork for Ditches and Embankments.

Reference: Page 434, § 470.

Directions: Find the area of each cross-section in succession, either by the use of the planimeter or by calculation, and apply the "end area" formula to the solids between the respective cross-sections as explained in § 470.

Note: If desired, the problems may also be solved by the "prismoidal formula." The problems are made simple purposely, it being taken for granted that, in most cases, the student will study this part of the subject to better advantage in connection with railway surveying.

PROBLEMS.

351. A ditch is 8.0 ft. wide at the bottom, and falls 0.5 ft. in 100 ft.; its sides slope outward 1½ horizontal to 1 vertical. The elevation at the bottom of the ditch at **0 + 0** = 20.0 ft. The elevations of the three points on the surface of the ground at each station are as follows: at **0 + 0**, C (the center height) = 32.1 ft., R (the right-hand edge of the ditch) = 31.1 ft., L (the left-hand edge of the ditch) = 33.6 ft.; at **0 + 50**, C = 31.6 ft., R = 30.8 ft., L = 32.4 ft.; at **1 + 00**, C = 30.1 ft., R = 28.7 ft., L = 31.0 ft.; at **1 + 50**, C = 28.2 ft., R = 26.4 ft., L = 29.1 ft.; at **2 + 00**, C = 24.3 ft., R = 23.1 ft., L = 25.3 ft. Calculate the earth to be removed from the portion of the ditch given above.

352. Same as Problem 351 except the bottom of the ditch is 10.0 ft. wide and the sides slope outward 1¼ horizontal to 1 vertical.

353. Assume the elevations on the surface of the ground to be the same as in Problem 351. It is desired to build an embankment, the top of which is 8.0 ft. wide and at an elevation of 36.0 ft. The sides slope 1½ horizontal to 1 vertical. Calculate the total fill.

354. Same as Problem 353 except the top of the embankment is 10.0 ft. wide and at an elevation of 38.0 ft. The sides slope 1¼ horizontal to 1 vertical.

Questions: 1. Define prismoid. 2. A transverse slope is denoted by the horizontal distance which corresponds to a vertical distance of one unit. How does this differ from the method ordinarily used in denoting a longitudinal slope (commonly called "grade")? 3. Give the "end area" formula. 4. Give the "prismoidal" formula. 5. Which gives the better results? 6. In the "prismoidal" formula is the area *M* the mean of the two end areas; how is it obtained? 7. What is meant by "three-level" cross-sections? 8. For "three-level" sections how may the work of computation be shortened?

Exercise E-6.

To Estimate Cut and Fill from a Contour Map.

Reference: Page 435.

Directions: The problem in this exercise is to estimate the cut and fill from a contour map, using one or more methods explained in § 471, p. 435. A contour map already plotted may be used, or a fictitious map similar to that shown in Fig. 471 (a), p. 435, may be drawn and used as a basis for computation.

Questions: 1. Explain in detail the first method, p. 435. 2. Explain the second method, p. 436. 3. Explain the third method, p. 436, illustrating it by means of a sketch.

GROUP P.

EXERCISES IN PLOTTING.

Exercise P-1.

Use of Drawing Instruments.

References: Pages 438 to 442 and pages 445 to 449.

Preparations of instruments: 1. First of all, *sharpen the pencil properly and then keep it sharp.* See remark, p. 438. Every student is required to keep at hand a piece of sandpaper and a cloth which may be suspended from the corner of the drawing table for convenience. 2. Insert a *hard* lead in the compasses and sharpen it to a *cone shape* point. See p. 442, § 478 (1). 3. Adjust the pivot needle, p. 442, § 478 (2). 4. Make a pricking point by inserting a needle in a wooden or a wax handle. See p. 418, § 486. 5. Test the edge of the T-square for straightness. See footnote, p. 438. 6. Test the right hand edge of the drawing board for straightness by bringing the upper edge of the T-square into contact with it. In a similar manner see if the surface of the board is a plane. 7. Test the triangles as directed in the footnote, p. 439. 8. Either during this exercise or previous to the next exercise, the student should prepare a protractor similar to that described on p. 456, § 493 (c).

Note: While the student is supposed to have had a course in mechanical drawing before beginning this course, nevertheless, it will be found advantageous to devote the first exercise in plotting to a drill in those methods of drafting which are of especial importance in mapping. The exercise will be of little value, however, unless the student is careful to observe the precautions outlined above, precautions which, if taken throughout the course, will enable him to secure more accurate results than he otherwise could. Additional suggestions for drafting should be reviewed in a recitation on the questions given at the end of this exercise.

PROBLEMS.

361. (1) Draw a horizontal line about 10″ long. (Read § 483, p. 446.) (2) Set the zero mark of the scale at an assumed point *A* on the horizontal line, and *without moving the scale* lay off in succession to a scale of 1″ = 20′ – 0″ the following distances:

$AB = 30$ ft., $BC = 42$ ft., $CD = 65.5$ ft., and $DE = 21.5$ ft. Check: $AE = 159.0$ ft. (Read § 475, p. 440, and § 486, p. 448.) (3) Draw a second horizontal line about 10″ long, and in a similar manner lay off (to a scale of 1″=40′–0″): 0 + 40, 0 + 60, 1 + 10, 1 + 75, 2 + 38, 3 + 17. (Read § 486 (a), p. 449.)

Note: In inspecting the above work the instructor will note: (1) If the pencil is sharpened correctly. (2) If fine, almost invisible prick-marks and freehand circles have been used. (3) If lengths are correct.

362. (1) Draw a line about 6″ long at 45° to the horizontal, and mark two points on it *A* and *B*, 128.2 ft. apart to a scale of 1″= 30′ – 0″. (2) By means of the compasses and scale, establish a point *C* 98.5 ft. from *A* and 120.6 ft. from *B*. Draw only *one* arc. (Read § 478, p. 442.)

Note: In inspecting the above work the instructor will note if the compasses were used correctly, and if the three lengths are correct. If a visible hole was left in the paper by the pivot needle of the compasses, it is evident that either the legs were not bent, or too much pressure was exerted.

363. (1) Draw a line at random about 10″ long and inclined *about* 10° to the horizontal. (2) Mark off on this line 421 ft. to a scale of 1″ = 50′–0″. (3) At one end of this length erect a perpendicular *about* 10″ long by using *two* triangles. (Read § 474 (1), p. 439.) (4) Lay off 328 ft. on this perpendicular. (5) Complete the 421 × 328 ft. rectangle without further measurement by drawing parallel lines with the two triangles. (Read § 474 (3), p. 439.) (6) Check the rectangle by measuring the lengths of the two diagonals.

Note: In inspecting the above work the instructor will note: (1) If light hair-lines have been used, and if the lines intersect sharply at corners, running beyond instead of stopping short. (2) If right methods of erecting perpendiculars and drawing parallel lines were employed. (3) If the lengths of the sides of a rectangle and of its diagonals are correct.

Questions: 1. What is the purpose of sharpening one end of the pencil to a wedge shape edge? p. 438. 2. How close to the ruling edge should pencil lines be drawn? p. 438. 3. Give additional suggestions for penciling, p. 446. 4. Give suggestions for the use of the T-square, p. 438. 5. Why should not the T-square be used against the top or bottom of the board for drawing vertical lines? p. 439. 6. What is the incorrect way of erecting a perpendicular line by means of a triangle? 7. How should the triangles be used for erecting perpendiculars; for drawing parallel lines? p. 439. 8. Explain the use of the decimal scale, p. 440. 9. Give additional suggestions for laying off measurements as regards marking points; use of dividers; arithmetical work; estimating fractions of a foot; setting the compasses to a given radius; detecting large errors; detecting small errors; avoiding the use of the wrong edge of the scale; laying off plus stations. p. 448. 10. What is the proper use of the dividers; the improper use; use of proportional dividers? p. 441. 11. Give suggestions for the use of the compass, p. 442. 12. Give suggestions for the use of the curve-ruler, p. 442. 13. Give suggestions for fastening the paper to the board, p. 445. 14. Give precautions to insure neatness, p. 445. 15. Give suggestions for erasing as regards erasing pencil lines; keeping the eraser clean; erasing ink lines; restoring the surface of the paper; use of an erasing shield; cleaning tracings. p. 447.

Exercise P-2.

Methods of Plotting Angles.

Reference: Chapter XXXVIII, p. 455.

Directions: The angles in each problem of this exercise should be plotted with as great accuracy as the method used in that problem will permit. Use hair-lines and prick the points.

PROBLEMS.

371. Draw a horizontal line 396 ft. long to a scale of 1″ = 50′ − 0″. By means of the protractor lay off at one end of this line an angle of 38° 20′ and at the other end an angle of 51° 40′. The two lines thus obtained and the original line should form a right-angled triangle; test the right angle by means of the two instrumental triangles. (In using the protractor, minutes of arc are estimated.)

372. Same as Problem 371 except use the tangent method for plotting angles, p. 458.

373. Same as Problem 371 except use the cosine and sine method, p. 459.

374. Same as Problem 371 except use the chord method, p. 459.

375. Compare the results by drawing an arc of 6″ radius for each of the angles in the above problems, and by means of the dividers see if the corresponding chords are of the same length in all four figures.

Questions: 1. Name five methods of plotting angles, p. 455. 2. Give suggestions for centering the protractor, p. 455. 3. Give three methods of laying off an angle greater than 180°, p. 456. 4. How closely can angles be plotted with an ordinary protractor? p. 456. 5. What is a vernier protractor? p. 456. 6. What is the advantage of the form of protractor shown on p. 456? 7. Give suggestions for making such a protractor, p. 457. 8. Explain the tangent method of plotting angles, p. 458. 9. Why is it advantageous to use a 10″ base? 10. When an angle exceeds 45° how is it plotted? 11. Explain methods of plotting angles a little greater or less than 90°; 180°; 270°. 12. Give practical suggestions as regards erecting perpendiculars; laying off hundredths of an inch; using a base larger or smaller than 10 inches; checking angles roughly; detecting small mistakes; laying off angles in the field. p. 459. 13. Explain the cosine and sine method of plotting angles and give the check, p. 459. 14. Explain the chord method of plotting angles, p. 459. 15. Give practical suggestions for the chord method as regards use of beam compasses and scale; a home-made device; use of 5″ radius; use of 8″, 9″, or 12″ radius. 16. Explain why, if the radius is 10″ and fiftieths on the scale are used, it is not necessary to multiply the sine of half the angle by 2. See Fig. 496 (c), p. 460. 17. What is the largest angle that can be laid off conveniently by the chord method without erecting a perpendicular? 18. Compare the different methods of plotting angles, p. 461. 19. Explain the three-point problem in plotting by the graphic method; by the algebraic method.

Methods of Plotting Traverses.

(Introductory.)

Before beginning to plot surveys from notes taken in the field, it is well for the student to have a preliminary drill in the different methods of plotting traverses. For this purpose it is advisable to select a polygon of four or five sides from among the problems given on p. 122,* and to plot this polygon by each of the general methods explained in Chapter XXXIX, p. 463. He will thus obtain a knowledge of the advantages and disadvantages of the different methods when applied to the same polygon. As pointed out on p. 463, for each of the four methods of plotting traverse lines there are four methods of plotting angles, but it is not worth while to plot the polygon sixteen times for the sake of illustrating each of these methods since many of them are so nearly alike. The methods chosen for the seven succeeding exercises have been selected with a view of bringing out the most important points connected with plotting traverses. In each exercise the choice of scale is left to the student or to the instructor. If desired, different scales may be employed for the different problems, care being taken that the scale is not so large that the polygon will run off the paper, or so small that the accuracy of the work is impaired. It is not advisable to ink the drawings, as time can be spent to better advantage in other work.

Exercise P-3.

Plotting Traverses with a Protractor.

Reference: Page 464, § 502.

Directions: 1. Assume one side of the polygon in any position on the paper that will permit the rest of the polygon to be plotted without running off the paper. 2. Plot the polygon, using the protractor for laying off angles, and the scale for laying off lengths. 3. Not only should the line from the last station pass through the first station, but the distance from the former to the latter, as scaled on the drawing, should be equal to that given in the notes. The student should make this test when the polygon is completed.

Problem: Plot the polygon of Problem , p. (To be assigned by the instructor from the problems on p. 122.*)

Questions: 1. Why is it important to plot traverse lines with great accuracy? p. 463. 2. How great an error in feet may be caused by the width of a line? 3. When may a protractor be used consistently for plotting traverses? p. 464. 4. Give precautions for centering protractor, p. 464.

Exercise P-4.

Tangent Method of Plotting Traverses.

Reference: Page 464, § 503 (a).

Directions: 1. Make a rough freehand sketch in the note-book and enter on this sketch the lengths and the angles to be plotted. (Angles are not necessarily the same as those given in the notes.) Check this data before proceeding. 2. Make out a table corresponding to that at the top of p. 465. 3. Plot each of the transit lines in succession by the tangent method. Check each angle roughly with the protractor as soon as plotted. 4. Check the length as well as the direction of the last line.

Problem: Same as the problem in Exercise P-3 except that the tangent method is used for plotting angles.

Questions: 1. Explain the tangent method of plotting traverses, p. 465. 2. If the closing line passes through the first station and is of the right length on the drawing, what additional check may be applied? p. 465. 3. When a traverse has a large number of sides, what check should be applied at every fourth or fifth station? p. 466, § 503 (c).

Exercise P-5.

Chord Method of Plotting Traverses.

Reference: Page 465, § 503 (b).

Directions: Same as for the preceding exercise except that the table made out in the note-book corresponds to that at the bottom of p. 465. It may also be advisable to plot deflection angles at stations where the interior angles are very obtuse.

Problem: Same as the problem in Exercise P-3 except that that the chord method is used for plotting angles.

Questions: 1. Explain the chord method for plotting traverses. p. 465. 2. Give the checks to be employed in this method. p. 466. 3. Give the method of plotting by deflection angles. p. 466.

Exercise P-6.

Plotting Traverses by Bearings.

(Tangent Method.)

Reference: Page 467, § 505.

Directions: 1. If the bearings of the lines are not given, calculate them from the angles at the stations. 2. Make a sketch in the note-book showing the bearing of each line and its length. 3. Prepare a table in the note-book corresponding to that at the top of p. 469. 4. Find the direction of each line from its bearing by the method illustrated in Fig. 505 (a), p. 468, or Fig. 505 (b), p. 469, preferably the latter method. Whichever method is used do not fail to test the square and to mark each line as soon as obtained with its letters or its numbers as shown in the figures referred to above. 5. Plot the polygon in any position which will bring it wholly within the limits of the paper, by transferring the direction of each line of the polygon to its proper place in the plot. Check each angle of the polygon roughly as soon as it is obtained, using the protractor for this purpose. 6. Apply the usual tests to the closing line.

Problem: Same as the problem in Exercise P-3 except that the sides of the polygon are plotted from their bearings by the tangent method.

Questions: 1. Explain the general method of plotting traverses by bearings. p. 467. 2. What bearings are plotted? See Note, p. 467. 3. Give two general methods of procedure. p. 467. 4. In either method what is the most convenient meridian to assume? p. 467. 5. When is it convenient to use a T-square with an adjustable head? p. 468. 6. Explain the tangent method of plotting bearings. p. 468. 7. Explain the corresponding modified method, p. 469. 8. Explain the chord method of plotting bearings. p. 469. 9. Explain the corresponding modified method. p. 470. 10. Give the checks to be employed. p. 471. 11. Give one of the chief objections to plotting traverses by bearings. p. 471. 12. To what kind of work is this method best suited?

Exercise P-7.

Plotting Traverses by Bearings.

(Chord Method.)

Reference: Page 469, § 505 (c) and § 505 (e).

Directions: This exercise might be made exactly like the preceding exercise, using the chord method instead of the tangent method in plotting bearings. This would involve little that is new, hence it is better to employ the method of § 505 (e), p. 470, drawing a new meridian at each station. Follow the directions of the preceding exercise except where they conflict with the method used in this exercise.

Problem: Same as the problem in Exercise P-3 except that the sides of the polygon are plotted from their bearings, a reference meridian being drawn at each station and the corresponding bearing plotted by the chord method.

Questions: 1. Explain the method of plotting bearings from a reference meridian at each station. p. 470. 2. Compare this method with the method of the preceding exercise. 3. Outline another method sometimes used for large maps. p. 471. 4. What is the advantage of this method?

Exercise P-8.

Plotting Traverses by Azimuths.

Reference: Page 471, § 506.

Directions: 1. Change the bearings of the sides of the polygon in the preceding exercise to azimuths. 2. Make a freehand sketch in the note-book, giving the azimuth and length of each line, and the angle which will be plotted at each station. 3. Use either the tangent or chord method for plotting the angles, preparing in advance a table of tangents or of chords to correspond. Apply the usual checks throughout the work.

Problem: Same as the preceding exercise except azimuths are plotted instead of bearings. As this in itself involves little that is new, it is desirable to use a method of plotting not employed in either of the two preceding problems. For example, the azimuths may be plotted by the tangent method from meridians drawn through the stations.

Exercise P-9.

Plotting Traverses by Latitudes and Departures.

Reference: Pages 471 to 475, § 507.

Directions: Follow the method of procedure outlined on p. 472, § 507 (b), observing also the practical suggestions at the top of p. 475.

Problem: Same as the problem in Exercise P-3 except that the polygon is plotted by the method of latitudes and departures.

Questions: 1. What bearings are used in computing latitudes and departures, calculated or magnetic? p. 471. 2. Without going into detail, what is the general method of plotting by latitudes and departures? p. 471. 3. Why is the most westerly station the most convenient reference point? p. 471. 4. Could any other reference point be used? 5. If azimuths are given in field notes instead of bearings, is it necessary to reduce them to bearings before calculating latitudes and departures? p. 472. 6. Explain three different methods of determining which is the most westerly station. p. 472. 7. Outline in detail the general method of plotting by latitudes and departures. p. 472. 8. What is the object in using a reference-rectangle and measuring from the two nearest sides to locate a point instead of locating it by coördinates by means of a T-square and triangles? p. 473, "Caution." 9. Give practical suggestions for plotting by latitudes and departures as regards (1) plotting large maps; (2) assuming the reference-rectangle so that no side is horizontal or vertical; (3) testing the rectangle; (4) plotting each station by its latitude and departure from the preceding station, and the advantage of this method; (5) advantage of drawing the traverse lines so that they stop just short of each station. p. 475. 10. What checks may be employed in this method of plotting? p. 475.

Methods of Plotting Traverses Compared: 1. Compare the tangent method and the chord method. p. 475. 2. What is the chief advantage in plotting direct angles or deflection angles instead of bearings or azimuths? p. 475. 3. What are some of the disadvantages of the direct angle method? p. 475. 4. When may the method of plotting by bearings be used? p. 476. 5. What are the advantages of plotting by latitudes and departures? p. 476.

Exercise P-10.

Plotting the Survey on Page 184.

Note: It will be found that the plotting of this survey is exceedingly good practice, as it involves nearly all the common methods of locating points which are used in the field. If desired, recitations Q-1 to Q-4 may be held in connection with this exercise.

Reference: Comments on the survey are given on p. 184; comments on the notes on p. 185. The notes themselves, however, are given on the inset sheet opposite to p. 190, Illustration V.

Directions: 1. Plot the transit lines first, using one of the trigonometric methods. 2. Plot the details, using the scale and protractor.

Problem: Plot the survey shown on the inset sheet opposite p. 190, Illustration 5. Choose a scale as large as practicable and still have the map fall within the limits of the paper.

GROUP Q.

QUESTIONS PERTAINING TO MAPPING.

Plotting Maps from Field Notes.

(Introductory).

In most courses in surveying students are required to plot maps from their own notes taken in the field. The preliminary drill in plotting having been completed and this work of plotting field notes having been begun, it is well to hold recitations from time to time on that part of the mapping in which the student is engaged. Thus, for example, before beginning to work up the notes preparatory to plotting, it is well to cover the ground outlined by the questions in Exercise Q–1. Before beginning to plot, the questions in Exercises Q–2 and Q–3 may be discussed. Before beginning to plot details, Exercise Q–4 may be taken up, and when the map is finally completed in pencil and ready to ink, questions on finishing the map may be discussed.

Exercise Q–1.

Working Up Field Notes Preparatory to Plotting.

Questions: 1. What is one of the first things to do in working up notes? p. 477. 2. In addition to saving time what other object is there in getting together all data and in making all the preliminary calculations before beginning to plot? p. 473. 3. When is it most necessary to correct field measurements? p. 478. 4. What are some of the corrections applied to linear measurements? to angular measurements? p. 478. 5. For what purpose are measurements adjusted? p. 478. 6. How may linear measurements be adjusted? angular measurements? p. 478. 7. It is often best not to follow any rule in adjusting angles. How is this illustrated by the survey on p. 390? p. 479. 8. In work of great precision how are observed values adjusted? p. 479. 9. What can you say regarding the calculation of bearings: for purposes of plotting; true bearings; use of adjusted values in angles; bearings in compass surveys? p. 479. 10. What methods are used for supplying missing data and what is the disadvantage in the use of these methods? p. 480. 11. Explain the method of reducing stadia notes by the use of reduction tables; by means of a diagram.* p. 481. 12. Why should the abridged method of multiplication be used in connection with reduction tables? 13. Summarize the first five or six steps in preparing data for plotting. p. 483. 14. Give the additional steps, p. 484, for (a) protractor method; (b) tangent method; (c) chord method; (d) latitude and departure method; (e) azimuth method.

Exercise Q-2.

Plotting the Map.

(General Methods and Suggestions.)

Questions: 1. What is the best kind of paper for map work? p. 485. 2. What is the best paper for maps that are to be tinted; for maps to be reproduced? p. 485. 3. What are the advantages and disadvantages of the different kinds of blue print paper? p. 485. 4. What are the most essential requirements for drawing instruments? p. 486. 5. Give some of the precautions to be taken in accurate plotting. p. 486. 6. What effect has the shrinkage of the paper and how may shrinkage be partly avoided? p. 486. 7. Why should maps be kept flat? p. 487. 8. Give the general methods employed in mapping. p. 487. 9. Give the general method of procedure. p. 487. 10. What are the most common scales for ordinary maps? p. 488. 11. Why are not the scales of 70 and 90 ft. to the inch commonly used? p. 488. 12. What is the so-called natural scale and what are some of the scales used for government work? p. 488. 13. Give some of the primary considerations in choosing a scale and illustrate by examples. p. 489. 14. Give some of the common scales used: for preliminary surveys of railroads; maps of mines and mining claims; maps for architects. p. 489. 15. What are the advantages of the scales 1 in. = 20 ft., 1 in. = 40 ft., and 1 in. = 80 ft.? p. 489. 16. What are some of the considerations which sometimes determine the size of the sheet? p. 489. 17. How does the arrangement of the map affect the size of the sheet? p. 489.

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* If desired, the student may be required to construct a diagram.

18. How may the shape and extent of a survey be determined roughly? p. 489. 19. Give two general rules for choosing the scale for a map. p. 490. 20. Why is it advantageous to adopt a small scale for topographic maps? p. 490. 21. What is the object in sometimes drawing maps of the same territory to different scales? p. 490. 22. What arrangement of the map is desirable as regards points of the compass? p. 490. 23. Why is this arrangement seldom economical? 24. What effect has the natural approach to a piece of property on the arrangement of the map? p. 490. 25. What is usually the first step in beginning a map? p. 490. 26. Where do you begin to plot a map and why work half way around a polygon in either direction? p. 491. 27. Give suggestions for assuming the first line. p. 491. 28. When it is desired to economize space and the map is plotted by latitudes and departures how would you proceed in assuming a reference-meridian, or reference-rectangle? p. 491. 29. When is a preliminary plot unnecessary? p. 491.

Exercise Q–3.

Plotting Traverses.

(Review.)

Questions: 1. To what do the different methods of plotting traverses correspond? p. 492. 2. In plotting traverses when is the protractor used? 3. What are the other methods used for plotting traverses? 4. Why should traverse lines be plotted accurately? 5. Summarize five methods of plotting transit lines, giving the checks used in each: (1) each line plotted from the preceding line, p. 492; (2) each line plotted by deflection angle, p. 493; (3) each line plotted from its bearing, p. 493; (4) each line plotted from its azimuth, p. 493; (5) transit lines plotted from latitudes and departures, p. 493. 6. Give the methods of checking linear measurements: (1) any straight line; (2) comparing the lengths of lines with corresponding distances in field notes; (3) checking lines of a traverse; (4) checking two points by indirect measurements. 7. Give the checks for angles: (1) when laid off with a protractor; (2) test for two or more adjacent angles; (3) check for angles plotted by trigonometric method; (4) checking angles between traverse lines. 8. Answer question on p. 495. 9. Give combination checks: (1) for a reference-rectangle; (2) for a closed traverse; (3) for extra distances taken in the field, p. 495. 10. Give methods of running down errors, p. 495: (1) when the error of closure is parallel or perpendicular to some line in the traverse; (2) when a traverse has been plotted by direct angles; (3) when the direction of the closing line is found to be incorrect; (4) when lines have been plotted by bearings or azimuths; (5) when a point is wrong and the mistake not easily found; (6) effect of long lines and lines north and south or east and west. 11. Give the different methods of plotting a triangulation net. p. 491.

Exercise Q-4.

Plotting Details.

Questions: 1. Give the methods of plotting points located by angles and distances, p. 496. 2. What precautions should be taken to avoid confusion? 3. Give the methods of plotting points located by angles. 4. Give the method of plotting points by linear methods only. 5. How may the straightness of a line located by offsets be tested? 6. Give general suggestions for keeping the drawing free from unnecessary lines, p. 496; for testing check distances; for plotting important points at a station; for plotting doubtful points, p. 497. 7. Explain the graphic method of interpolating contours. p. 497. 8. Why, as a rule, will a point interpolated from two given points be different if interpolated between two other points. Remark, p. 497. 9. Explain the tracing cloth method of interpolating contours. p. 497. 10. Give suggestions for the use of this method. p. 498. 11. Describe a home-made device for interpolating contours. p. 498. 12. What determines the accuracy required in plotting? and give illustrations. p. 499. 13. What contributes to speed in plotting? p. 499. 14. Give the different methods of copying and transferring maps. p. 500. 15. Which methods are used for copying to a different scale from that of the original map. p. 501.

Exercise Q-5.

Finishing the Map.

Questions: 1. In finishing a map what are some of the specifications for workmanship? p. 502. 2. What in general should appear on a map? p. 502. 3. When is the scale of the map shown by a drawing instead of being given in figures? p. 502. 4. Is a magnetic meridian always shown? p. 502. 5. What are the most important requirements for an ordinary property map? p. 502. 6. What are some of the additional requirements prescribed by law in some states? Remark, p. 503. 7. Give some of the requirements for topographic maps. p. 503. 8. Give some of the things which should appear on a map made for an architect. p. 211. 9. Give the general method of procedure in finishing a map. p. 503. 10. Give suggestions for arrangement of (a) border lines, p. 504; (b) lettering, p. 505; (c) titles, p. 505; (d) names of streets, streams, property owners, etc., p. 505; (e) give additional suggestions for arrangement, p. 505.

Questions on Inking: 1. Give suggestions for the use of a ruling pen as regards (1) producing clear-cut lines, p. 440; (2) method of holding the pen, p. 440; (3) adjusting the nibs of the pen, p. 441; (4) cleaning the nibs; (5) sharpening the pen; (6) method of inking straight lines (Suggestions (5), (6), and (7), p. 446); (7) order of inking straight lines and circles, p. 447; (8) inking lines that meet in a point, p. 447; (9) inking wide lines, p. 447; (10) mixing india ink, p. 447. 2. Give additional suggestions for inking as regards (1) order of inking lines, p. 506; (2) inking edges of streams and similar indefinite lines, p. 506; (3) inking traverse lines, p. 506; (4) inking broken lines. 3. Give the method of outline shading. p. 506. 4. Give suggestions for the use of colored inks. p. 506.

Questions on Tracing: 1. Give general suggestions for tracing as regards (1) which side of the cloth to use, p. 451; (2) preparation of the tracing cloth, p. 451; (3) effect of too fine lines and figures on the blue print, p. 451; (4) precautions to be taken in erasing on tracing cloth, p. 452; (5) inserting new pieces of cloth, p. 452; (6) effect of moisture on tracing cloth, p. 452; (7) use of tracing paper instead of tracing cloth, p. 452; (8) best ink to use, p. 452; (9) method of cleaning a tracing,

p. 452. 2. What are the printing qualities of different colored inks? p. 507. 3. How may tracings be colored with pencils? p. 507. 4. How should streams and shore lines be colored? p. 507. 5. Give method of lettering tracings by shifting letters underneath. p. 517.

Questions on Lettering: 1. Upon what does good lettering mostly depend? p. 507. 2. What defects in lettering are the least excusable? p. 508. 3. Give some suggestions as regards style of letters. p. 508. 4. Give general method of lettering. p. 509. 5. Give suggestions as regards the size of letters. p. 509. 6. Give suggestions as regards the proportions of letters. p. 510. 7. Give suggestions for penciling the letters as regards (1) use of guide lines, p. 510; (2) estimating the unit for proportioning; (3) blocking out letters; (4) two things to observe in drawing letters, p. 511; (5) devices for lettering on tracing cloth, p. 511. 8. Give the most important points to be remembered in the construction of the various letters.* p. 511. 9. Give suggestions for inking letters as regards: pens used, p. 515; inking outlines of letters; filling in; touching up imperfect corners; testing the pen; precautions for keeping the ink. 10. What are the most common defects in lettering? p. 516. 11. Give suggestions for spacing letters on paper; on tracings. p. 516. 12. Give general suggestions for lettering maps as regards (1) general arrangement, p. 517; (2) lettering curved streets or winding rivers; (3) arrangement of two lines that are not centered; (4) positions of names and descriptions; (5) printing values of small angles and of a decimal of a foot; (6) distinguishing between angular measurements and linear measurements, p. 518; (7) indicating the forward bearing for a line. 13. Give six different methods of making lettering more prominent. p. 518.

Finishing Topographic Maps: 1. Give suggestions for drawing contour-lines as regards (1) color of ink, p. 518; (2) width of lines and kind of pen used; (3) which contours are accentuated; (4) marking elevations of accentuated contours; (5) breaks in contour-lines, p. 519; (6) representing intermediate contours. 2. What are some of the common mistakes in drawing contours? p. 519, p. 338. 3. Give suggestions for conventional signs.* p. 519. 4. Give method of drawing small water courses. p. 519. 5. Give suggestions for water-lining, p. 522. 6. Give suggestions for section-lining. p. 522.

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* This study of the Gothic capitals is best made in connection with a regular course in lettering, or at least in separate exercises devoted to practice in proportioning letters.

Questions on Tinting. (See p. 449.) 1. Give the method of mixing the tint. 2. What is the effect of pencil lines? p. 450. 3. Should the drawing be tinted first or inked first? 4. Give suggestions for applying the tint. p. 450. 5. What is the secret of success in tinting? p. 450. 6. How may the tint be removed from outside the boundary line? 7. How may the surplus tint be removed? 8. Why is it well to go over the surface first with clean water? p. 451. 9. What is the best method of securing a dark tint? 10. To what is tinting on ordinary maps usually confined? p. 523. 11. Give some of the conventional tints.

Questions on Border-Lines and Titles: 1. (p. 523.) Give general suggestions for drawing border-lines as regards: simplicity; size of rectangle; width of heaviest border-line; method of drawing a heavy border-line. 2. Where is the best place for a title? 3. On what does the size of the largest letters depend? 4. What is the first consideration in designing a title? 5. Give suggestions for: arranging subject-matter; making some lines more prominent than others; centering lines; spacing lines; making lines of unequal length; styles of lettering. 6. Should lower-case letters be used? p. 524. 7. Is it well to make part of the letters inclined and part upright? 8. For what is single-stroke lettering used? 9. When should the title be drawn freehand and when with instruments? 10. Should words be abbreviated in a title? 11. How may a title be centered on tracing cloth? 12. What are some of the mechanical devices for printing titles? 13. What should appear in a title? p. 525. 14. Give the general method of procedure in constructing a title. p. 525.

Questions on Meridian Needles, Scales, etc.: 1. How is the true north distinguished from the magnetic north? p. 526. 2. How is the direction of the arrows determined? 3. Why should the magnetic declination be given in figures, if given at all? 4. How is the scale usually given? 5. When is it most necessary to represent it by a drawing, and what is the chief advantage of this? 6. What is the purpose of keys or legends?

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* A plate of conventional signs may well be drawn either in a separate exercise or in connection with a course in lettering.

7. When should explanatory notes be used and where should they be placed? 8. How may the paper be cleaned when maps are finished; how may tracings be cleaned? 9. What are some of the things that should be stated in a surveyor's certificate? p. 527. 10. By looking up some of the references on p. 528, give the most essential elements of a good filing system.

Exercise Q-6.*

Profiles.

Questions: 1. In plotting profiles, is it customary to use the same scale for laying off elevations that is used for horizontal distances? p. 529. 2. When does a profile represent a true vertical section and when does it not? p. 530. 3: Why are profiles apt to be misleading? Remark, p. 530. 4. What are the three standard styles of profile paper? p. 530. 5. Give suggestions for the choice of scale. p. 531. 6. What are some of the most convenient combinations of papers and scales? p. 531. 7. Give the method of working up notes for profiles, including the checks. p. 531. 8. Give suggestions for method of procedure in plotting profiles as regards: assuming the position and elevation of base-line, p. 532; where to begin the profile; how to make 100-ft. stations fall on accentuated vertical lines; how to number accentuated lines, vertical and horizontal; how to plot points; how to check points. 9. Give additional suggestions for: two men working to advantage, p. 533; marking points; continuing a profile which runs off the bottom or top of the paper; avoiding the common mistake of plotting turning-points and benches; plotting accurate profiles; making several copies of profiles. 10. Give examples of the method of plotting the profiles of several related lines. p. 533. 11. Give the method of laying out grades and vertical curves on profile. p. 533. 12. Give suggestions for finishing profiles as regards: representing existing surfaces and proposed changes; ruling the profile or drawing it freehand; smoothing out sharp angles; inking the base-line; methods of marking elevations; the points at which elevations should be marked; marking cut or fill; marking rate of grade; tinting or coloring profiles; method of showing different materials. 13. Give suggestions for lettering profiles. p. 535.

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* Recitation to be held in connection with an exercise in plotting profiles.

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Ditto, stronger, with painted divisions . . .	3	3	0
Gravatt's Levelling Staff	4	4	0

	£	s.	d.
Tape Measure, 25 feet, links	0	7	0
Ditto, ditto, decimals	0	8	0
Ditto, 33 feet, links	0	8	0
Ditto, ditto, decimals	0	9	0
Ditto, 50 feet, links	0	10	0
Ditto, ditto, decimals	0	12	0
Ditto, 66 feet, links	0	12	0
Ditto, ditto, decimals	0	14	0
Ditto, 100 feet, links	0	16	0
Ditto, ditto, decimals	0	18	0
Land Chains, 50 feet, and Arrows	0	13	6
Ditto, 100 feet, and ditto . . from 1*l.* 3*s.* 6*d.* to	1	5	0
Ditto, 66 feet, with two Round Rings between each link and Arrows	0	15	6
[illegible]tto, ditto, with three Round Rings, &c. . . .	0	17	6

	£	s.	d.
Four-inch best Theodolite (Captain Dawson's)	21	0	0
Five-inch Cradle ditto	21	0	0
Five-inch ditto (best construction,) divided on Silver, with Tangent-screw Motions	25	4	0
Five-inch ditto ditto, with two Telescopes	31	10	0
Six-inch ditto, with one Telescope, divided to 20 seconds, complete	31	10	0
Six-inch ditto, with two Telescopes	40	0	0
Six-inch ditto, with Transit Axis and Vertical Circle	36	15	0
Six-inch ditto (Captain J. T. Boileau's construction,) with Axis, Level, &c.	42	0	0
Seven-inch ditto, with one Telescope	35	14	0
Seven-inch ditto, with two Telescopes	45	0	0
Eight-inch ditto, Azimuth and Altitude, with Axis, Level, &c.	52	10	0
Twelve-inch ditto, for Horizontal Angles only	42	0	0
Four-inch ditto (Col. Everest's construction)	22	0	0
Five-inch ditto, ditto	26	5	0
Seven-inch ditto, ditto	36	15	0
Five-and-a-half-inch Kater's Circle, with Stand, complete	35	0	0
Small Kater's Circle, with Stand	16	0	0
Level Collimator . . . from 10*l.* 10*s.* to	15	15	0

(Larger Theodolites, &c., made to Order.)

STATION POINTERS, PROTRACTORS, PENTAGRAPHS, ETC.

	£	s.	d.
Twelve-inch Station Pointer	6	16	6
Eighteen-inch ditto	7	17	6
Two-feet ditto	9	9	0
Thirty-inch ditto	12	12	0
Three-feet ditto	18	18	0
Wollaston's Goniometer	2	13	6
Eight-inch best Brass Circular Protractor, with Clamp and Tangent Screw and folding Arms	7	7	0
Ditto, ditto, divided upon Silver	8	8	0
Six-inch ditto, with Rack and Pinion	4	14	6
Ditto, ditto, divided upon Silver	5	15	6
Six-inch Semicircular Protractor, with Vernier and Arm	3	3	0
Eight-inch ditto, ditto	3	13	6
Fifteen-inch plain Circular Protractor	3	5	0
Eight-inch ditto . . . from 1*l.* 5*s.* to	1	11	

	£	s.	d.
Level with Sights and Socket, in Box	1	11	6
Portable Levelling Instrument, with Telescope	8	8	0
Ditto, with Compass, &c.	9	9	0
Fourteen-inch improved Level, with Round Legs	11	11	0
Ditto, with Tripod Stand	12	12	0
Twenty-inch ditto, with Round Legs	13	13	0
Ditto ditto, with Tripod Stand	14	14	0
Y Levels, with nine-inch Telescope	10	10	0
Ditto, with twenty-inch ditto	16	16	0
Ditto, with ditto and Compass	17	17	0
Gravatt's Dumpy Level, without Legs or Compass	12	12	0
Ditto, with Silver Ring Compass and Round Legs	15	15	0
Ditto, with Tripod Stand and Silver Ring Compass	16	16	0
Ditto, fourteen-inch, with Round Legs and Card Compass	15	15	0
Ditto, ditto, with Silver Ring Compass and Tripod Stand	17	17	0
Ditto, large size, complete	22	0	0
Standard Levelling Instrument	42	0	0
Plane Table, with Sights and Round Legs	6	16	6
Ditto, with Telescope, &c.	12	12	0
Cylindrical Cross Staff	0	16	0
Ditto, with Compass and Leg	2	12	6
Circumferenter, in Mahogany, without Legs	2	12	6
Ditto, ditto, larger size	4	4	0
Ditto, in Brass, with Round Legs from 4*l.* 14*s.* 6*d.* to	6	6	0
Ditto, ditto, with Ball and Socket Joint, and Round Legs	6	16	6
Ditto, with Rack Motion, divided to 3 minutes, Ball and Socket Joint and Round Legs	10	10	0
Ditto, ditto, with Levels and Levelling Plates	12	12	0
Best Brass Miners' Compass, with divided Cover, Ball and Socket Joint and Legs	7	17	6
Ditto, with Vertical Arc, Telescopic and Plain Sights, Levels in Compass, Rack Motion, &c., and Legs complete	16	16	0
Prismatic Compass, plain	3	3	0
Ditto, with Azimuth Glasses	3	13	6
Ditto, three-and-a-half inch, plain	3	13	6
Ditto, ditto, with Azimuth Glasses	4	4	0
Prismatic Compass, three-and-a-half inch, with Silver Ring	5	5	0
Stand for Prismatic Compass, with Ball and Socket Joint	1	11	6
Theodolite, with Telescope	14	14	0

	£	s.	d.
ox Sextant, Ordnance Pattern	5	5	0
itto, with Supplementary Arc	5	15	6
itto, with ditto, and Levels	6	6	0
Leather Case and Strap for Box Sextant	0	9	0
Metal Sextant, 4-inch Radius, divided on Silver to 20 seconds	10	10	0
Ditto, 5-inch ditto, to 20 seconds	13	13	0
Ditto, 6-inch ditto, to 20 seconds	14	14	0
Ditto, 7-inch ditto, to 10 seconds	16	16	0
Ditto, 8-inch ditto, with Double Frames, divided on Silver to 10 seconds	18	18	0
Ditto ditto, divided on Platina	21	0	0
Ditto ditto, divided on Gold	23	2	0
Dip Sector, as described in 'Treatise on Instruments,' by F. W. Simms	12	12	0
Troughton's Reflecting Circle	23	2	0
Six-inch Borda's Repeating Circle by Reflexion	21	0	0
Eight-inch ditto	23	2	0
Ten-inch ditto	25	0	0
Brass Counterpoise Stand for Circle or Sextant, in Mahogany Box	5	15	6
Glass Plane Artificial Horizons, two-and-a-quarter-inch diameter	1	11	6
Ditto, two-and-a-half-inch diameter	2	2	0
Ditto, three-inch diameter	3	3	0
Ditto, three-and-three-quarter inch	4	4	0
Ditto ditto, Ordnance Pattern	4	4	0
Best Mercurial Horizon, with Iron Bottle and Trough, Ordnance Pattern	5	5	0
Ditto ditto, smaller size	4	14	
Ditto ditto, with Brass Folding-roof	5	5	
Ditto ditto, with Ebony ditto	4	14	
Ditto ditto, with Mahogany ditto	4	4	
Marine Horizon (Captain Becher's)	5	5	

LEVELS, THEODOLITES, &c.

Four-inch Pocket Level	0	9	
h ditto	0	12	
	0	15	
	1	1	

	£	s.	d.
A Syren	2	2	0
A Small Still with Worm, Tub and Lamp	2	18	0
Set of Lactometers in Box	0	18	0
Glass Model of a Diving Bell . . . from 2*l.* 12*s.* 6*d.* to	7	7	0
Whirling Table complete	30	0	0
Hydrostatic Balance . . . from 2*l.* 2*s.*, 4*l.* 14*s.* 6*d.* to	8	18	6
Hydrostatic Paradox	7	7	0
Model of the Centrifugal Pump . . . from 4*l.* 10*s.* to	7	7	0
Sectional Model of a Steam Engine	18	0	0

(Models of Steam Engines, Machinery, &c., made to Order.)

	£	s.	d.
Bar Magnets for correcting the Derangement of the Compass in Iron Vessels, 2 feet each, 2*l.* 2*s.*; 14 inches each, 1*l.* 1*s.*; 8 inches	0	10	6

Magnetometers, Collimating and Referring Telescopes, for use in Magnetic and other Observatories.

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TROUGHTON AND SIMMS beg to caution those who may have occasion to write from abroad, that no reliance can be placed on the genuineness of the Instruments they obtain, unless the application be made *direct*, or through the most respectable channels.

APPARATUS.

	£	s.	d.
A Universal Discharger and Press	1	16	0
Jointed Discharger, with Glass Handles	0	12	6
Ditto, plain . . . . . from 4*s*. 6*d*. to	0	8	6
Exhausted Flask for showing the Aurora Borealis	0	8	6
Electrical Batteries of combined Jars . from 2*l*. 12*s*. 6*d*. to	10	10	0
Cuthbertson's Improved Electrometer, with Grain Weight	2	12	6
Bennet's Gold Leaf Electrometer	0	18	0
Cavallo's Bottle Electrometer, for Atmospherical purposes, from 12*s*. to	4	14	6
Quadrant Electrometer, with divided Arch	0	9	6
Kinnersley's Electrometer	1	1	0
Coulomb's Electrometer	1	16	0
Pith-Ball ditto	0	16	0
Luminous Conductors . . . from 12*s*. to	1	0	0
A Thunder-house, for showing the use of Conductors	0	8	0
Ditto ditto, with Draw	0	9	6
A Powder-house for ditto	0	16	0
An Obelisk or Pyramid for ditto	0	10	6
A Magic Picture for giving Shocks . from 7*s*. 6*d*. to	0	16	6
Spiral Tubes to illuminate by the Spark . from 8*s*. to	0	10	6
A Set of 5 Spiral Tubes on a Stand	1	16	0
Ditto, with a Dome	2	8	0
Luminous Names or Words . from 10*s*. 6*d*. to	1	11	6
A Set of 3 Plain Bells	0	10	6
A Set of 8 Bells, containing the Gamut	1	14	0
Diamond or Spotted Jars . . from 8*s*. to	0	16	0
A Double Jar for explaining the Franklinian Theory, from 18*s*. to	1	8	0
An Electrical Cannon	0	18	0
A Brass Electrical Pistol	0	9	6
Copper Plates and Stand for Dancing Images	0	10	6
A Small Head with Hair	0	8	0
An Artificial Spider	0	1	6
Sportsman and Birds	1	16	0

Atwood's Machine for Demonstrating the Law of Acceleration in Falling Bodies . . from 20*l*. to	30	0	0
Working Model of Locomotive Engine, 4 wheels	25	0	0
Ditto, 6 wheels	40	0	0

	£	s.	d.
Minimum Thermometer and Parabolic Reflector	2	10	0
Photometer (Leslie's)	3	3	0
Geothermometer	2	2	0

	£	s.	d.
Professor Leslie's Machine for making Ice	78	0	0
A ditto for ditto, with one Plate	48	0	0
A large Air-Pump, on a Stand, with Barometer Gauge	22	0	0
A large Table ditto, with Siphon Gauge	15	15	0
A Middle Size ditto, with ditto	9	9	0
A Small ditto, with ditto	6	16	6
A Single Barrel ditto from 1*l.* 11*s.* 6*d.* to	4	4	0

APPARATUS.

	£	s.	d.
Guinea and Feather Experiment, Receiver included	2	15	0
A set of Windmills from 1*l.* 15*s.* to	2	12	6
Apparatus for Freezing Water	1	4	0
A Bell for proving that without Air there is no sound, from 10*s.* 6*d.* to	1	11	6
Brass Hemispheres, to demonstrate external Pressure, from 20*s.* to	1	18	0
Model of a Water Pump	1	11	6
Double Transferrer	3	3	0
Single Transferrer, with Fountain Pipe	1	5	0
Glass Vessel for Fountain in Vacuo	0	7	0
Six Breaking Squares, Cage and Cap	0	18	0
Apparatus for striking Steel and Flint in Vacuo	0	18	0
Copper Bottle, Beam, and Stand, for weighing Air, and other Experiments	3	3	0
Model of Forcing Pumps for a constant stream, with glass barrels	3	3	0
Gun Lock Experiment	1	1	0
Bacchus ditto	1	14	6
Small-sized Japanned Copper Fountain, with Syringe and 5 Jets	7	0	0
Torricellian Experiments	0	10	6

	£	s.	d.
A twelve-inch Electrical Plate Machine, packed with Medical Apparatus	7	10	0
A fifteen-inch ditto, packed	10	10	0
An eighteen-inch ditto, packed	12	12	0
A two-feet ditto, packed	18	18	0
A Cylinder Machine, 16 by 10, packed	12	12	0
A ditto ditto, 14 by 8, packed	10	10	0

		£	*s.*	*d.*
Parallel Wire Micrometer, with Eye-piece, 8*l.* 8*s.*, 12*l.* 12*s.*, and		15	15	0
Twelve-inch improved Altitude and Azimuth Instrument divided on Silver, the Azimuth Circle Reading by Verniers, and the Altitude by Micrometers		105	0	0
Fifteen-inch ditto, both Circles with Reading Micrometers		130	0	0
Ditto, the Altitude Circle 18, and the Azimuth 15 inches with Micrometers		150	0	0
Ditto, both Circles 18 inches		210	0	0
Twelve-inch Repeating Circle (Borda's)		84	0	0
Eighteen-inch ditto (Borda's)		105	0	0

(Larger Transits and Circles to Order.)

		£	*s.*	*d.*
Tropical Tempest Sympiesometer		5	5	0
Sympiesometer		4	4	0
Marine Barometers.	from 4*l.* 4*s.* to	7	17	6
Chamber ditto	from 3*l.* 3*s.* to	6	6	0
Best ditto ditto, with Float Gauge		8	8	0
Standard Siphon Barometer		16	16	0
Wheel Barometer	from 4*l.* 4*s.* to	5	5	0
Mountain Barometer (Englefield's construction)		4	14	6
Ditto, ditto, with Long Scale		5	0	0
Leather Case for ditto		1	1	0
Mountain Barometer (Gay Lussac's)		7	17	6
Ditto, ditto, with Wire Stand, Ordnance Pattern		7	17	6
Ditto, ditto, Troughton's best construction		12	12	0
Wollaston's Thermometer, with Apparatus for Boiling Water, &c.		4	4	0
Thermometers, various	from 5*s.* to	1	15	0
Standard Thermometers	2*l.* 12*s.* 6*d.* and	3	3	0
Six's Self-Registering Thermometers	from 1*l.* 10*s.* to	2	2	0
Horizontal ditto (Maximum and Minimum)	from 15*s.* to	1	11	6
Day or Night ditto, singly	from 7*s.* 6*d.* to	0	13	0
Hygrometer, Pocket, Brass		0	13	0
Ditto, ditto, Gilt		0	18	0
Ditto (Mason's) Wet and Dry Bulb		0	18	0
Ditto, ditto, in Case, for Travellers		1	5	0
Ditto, Daniell's		2	12	6
Ditto, ditto, large Size		4	4	0
Rain-Gauge, Common		1	15	0
Ditto, Best		4	14	6

	£	s.	d.
Plain Ebony Parallel Rulers, 15 inches	0	7	0
Ditto ditto, 18 inches	0	9	0
Ditto ditto, 2 feet	0	12	6
Ditto, ditto, with Brass Edges, 18 inches	0	14	0
Ditto, ditto, ditto, 2 feet	1	1	0
Ditto, ditto, ditto, 2 feet 6 inches	1	11	6
Ditto ditto, ditto, 3 feet	2	2	0
Rolling Ebony Parallel Rulers, with Brass Edges, 12 inches	1	0	0
Ditto, ditto, ditto, 15 inches	1	5	0
Ditto, ditto, ditto, 18 inches	1	11	6
Rolling Ebony Parallel Rulers, with Plain Edges, per inch	0	1	0
Ditto, ditto, ditto, with Ivory Edges divided	0	1	6

HORIZONTAL DIALS MADE TO ANY LATITUDE.

	£	s.	d.
Six-inch to 5 minutes	1	1	0
Nine-inch to ditto	2	5	0
Twelve-inch to 2 minutes, and Equation Table	6	16	6
Twelve-inch, with Turned Edge, divided to two minutes, and Equation Table	7	7	0
Fifteen-inch, divided to 1 minute, without Turned Edge	7	17	6
Eighteen-inch, divided to 1 minute, 32 Points Lettered, Equation Table, &c., &c.	18	18	0

(Larger to Order.)

UNIVERSAL JOINT DIALS.

	£	s.	d.
wo-and-a-half-inch, in Case complete	2	2	0
ree-and-a-half-inch ditto	2	12	6
ur-and-a-half-inch ditto, with Levels in Compass	4	14	6

TRANSITS AND CIRCLES.

	£	s.	d.
enty-inch Transit Instrument, with Iron Stand	21	0	0
to, ditto, with graduated Scale to Level, &c.	23	2	0
-feet ditto, with Portable Brass Stand	26	5	0
-and-a-half-feet ditto, with Iron Stand	42	0	0
to, ditto, Improved	47	5	0
ee-and-a-half ditto, constructed for fixing upon Stone Piers, complete	84	0	0
tion Transit, best construction			

		£	s.	d.
Set of Marquois Scales, in Box		0	12	6
Ditto, in Ivory		2	5	0
Ditto, in Brass		2	12	6
Ditto, in Electrum		4	4	0
Twelve-inch Ivory Plotting Scales	from 11*s.* to	1	1	0
Twelve-inch Boxwood ditto	from 4*s.* to	0	7	0
Ivory Offsett and Pocket Scales	from 2*s.* 6*d.* to	0	6	6
Gunter's Scale, Brass, 2 feet		2	2	0
Ditto, Boxwood	from 5*s.* to	0	9	0
Ivory folding Rules	from 12*s.* to	0	18	0
Boxwood ditto	from 6*s.* 6*d.* to	0	15	0
Gunner's Rules	from 3*s.* to	0	10	6
Camera Lucida	from 1*l.* 11*s.* 6*d.* to	2	12	6
Stand for ditto	from 1*l.* 1*s.* to	1	11	6

		£	s.	d.
Drawing Instruments, in Skin Cases, (Sappers and Miners)		0	14	0
Ditto, ditto, East India Company's Pattern		1	5	0
Ditto, ditto, Woolwich pattern		1	15	0
Ditto, ditto, School Pattern		2	2	0
Ditto, ditto, Ordnance Pattern		3	3	0
Ditto, in Mahogany Cases, Addiscombe Pattern		3	3	0
Ditto, ditto, Admiralty Pattern		3	13	6
Ditto, ditto, Sector-jointed Instruments, Parallel Rulers, Sector and Protractor		3	13	6
Ditto, ditto, with Sector double-jointed Dividers		4	4	0
Ditto, ditto, with proportional Compasses		5	15	6
Ditto, ditto, with Spring Bows		7	7	0
Ditto, ditto, with Road and Wheel Pens, Needle-holder and small Dividers, &c.		9	9	0
Drawing Instruments in Electrum, packed in Rosewood and Mahogany Cases, of the best description,	from 5*l.* 5*s.* to	13	13	0
Ditto, ditto, large Magazine Cases		26	5	0
Proportional Compasses		1	11	6
Ditto, ditto, with Adjusting Screw		2	2	0
Plain Beam Compasses		1	15	0
Ditto, with Pen and Pencil Points		2	2	0
Plain Beam Compasses, Ordnance Pattern		2	12	6
Beam Compasses with Double Adjustments and Divided Beam	from 4*l.* 4*s.* to	6	6	0

		£	s.	d.
Semicircular plain Protractors	from 16*s.* to	2	2	0
Ivory Protractors	from 6*s.* to	0	15	0
Ditto, upon Parallel Rollers	from 18*s.* to	1	5	0
Eighteen-inch best Brass Pentagraph		5	5	0
Two-feet ditto		6	6	0
Two-and-a-half-feet ditto		7	7	0
Three-feet ditto		8	8	0
Three-and-a-half-feet ditto		9	9	0
Trochiameter, for counting the Revolutions of a Carriage-wheel		2	5	0
Leather Case with Strap for ditto		0	10	6
Plain Perambulators (Wood)		9	9	0
Ditto, Brass-mounted		12	12	0
Best ditto, with Metallic Wheel		16	16	0
Common twelve-feet Levelling-Staff		1	11	6
Best ditto		1	15	0
Troughton's Improved Portable ditto, with Level		2	12	6
Sopwith's ditto, for Reading without an Assistant		2	12	6
Ditto, stronger, with painted divisions		3	3	0
Gravatt's Levelling Staff		4	4	0

Tape Measure, 25 feet, links		0	7	0
Ditto, ditto, decimals		0	8	0
Ditto, 33 feet, links		0	8	0
Ditto, ditto, decimals		0	9	0
Ditto, 50 feet, links		0	10	0
Ditto, ditto, decimals		0	12	0
Ditto, 66 feet, links		0	12	0
Ditto, ditto, decimals		0	14	0
Ditto, 100 feet, links		0	16	0
Ditto, ditto, decimals		0	18	0
Land Chains, 50 feet, and Arrows		0	13	6
Ditto, 100 feet, and ditto	from 1*l.* 3*s.* 6*d.* to	1	5	0
Ditto, 66 feet, with two Round Rings between each link and Arrows		0	15	6
Ditto, ditto, with three Round Rings, &c.		0	17	6
Ditto, ditto, with two Oval Rings, &c.		0	18	0
Ditto, ditto, with three Oval Rings, &c.		1	1	0
Standard Chain, 50 feet	4*l.* 4*s.* and	5	5	0
Ditto, 66 feet	5*l.* 5*s.* and	6	16	6

	£	s.	d.
Four-inch best Theodolite (Captain Dawson's)	21	0	0
Five-inch Cradle ditto	21	0	0
Five-inch ditto (best construction,) divided on Silver, with Tangent-screw Motions	25	4	0
Five-inch ditto ditto, with two Telescopes	31	10	0
Six-inch ditto, with one Telescope, divided to 20 seconds, complete	31	10	0
Six-inch ditto, with two Telescopes	40	0	0
Six-inch ditto, with Transit Axis and Vertical Circle	30	15	0
Six-inch ditto (Captain J. T. Boileau's construction,) with Axis, Level, &c.	42	0	0
Seven-inch ditto, with one Telescope	35	14	0
Seven-inch ditto, with two Telescopes	45	0	0
Eight-inch ditto, Azimuth and Altitude, with Axis, Level, &c.	52	10	0
Twelve-inch ditto, for Horizontal Angles only	42	0	0
Four-inch ditto (Col. Everest's construction)	22	0	0
Five-inch ditto, ditto	26	5	0
Seven-inch ditto, ditto	36	15	0
Five-and-a-half-inch Kater's Circle, with Stand, complete	35	0	0
Small Kater's Circle, with Stand	16	0	0
Level Collimator . . . . from 10*l.* 10*s.* to	15	15	0

(Larger Theodolites, &c., made to Order.)

STATION POINTERS, PROTRACTORS, PENTAGRAPHS, ETC.

	£	s.	d.
Twelve-inch Station Pointer	6	16	6
Eighteen-inch ditto	7	17	6
Two-feet ditto	9	9	0
Thirty-inch ditto	12	12	0
Three-feet ditto	18	18	0
Wollaston's Goniometer	3	13	6
Eight-inch best Brass Circular Protractor, with Clamp and Tangent Screw and folding Arms	7	7	0
Ditto, ditto, divided upon Silver	8	8	0
Six-inch ditto, with Rack and Pinion	4	14	6
Ditto, ditto, divided upon Silver	5	15	6
Six-inch Semicircular Protractor, with Vernier and Arm	3	3	0
Eight-inch ditto, ditto	3	13	6
Fifteen-inch plain Circular Protractor	3	5	0
Eight-inch ditto . . . from 1*l.* 5*s.* to	1	11	6

	£	s.	d.
Level with Sights and Socket, in Box	1	11	6
Portable Levelling Instrument, with Telescope .	8	8	0
Ditto, with Compass, &c.	9	9	0
Fourteen-inch improved Level, with Round Legs .	11	11	0
Ditto, with Tripod Stand	12	12	0
Twenty-inch ditto, with Round Legs . . .	13	13	0
Ditto ditto, with Tripod Stand	14	14	0
Y Levels, with nine-inch Telescope . . .	10	10	0
Ditto, with twenty-inch ditto	16	16	0
Ditto, with ditto and Compass	17	17	0
Gravatt's Dumpy Level, without Legs or Compass .	12	12	0
Ditto, with Silver Ring Compass and Round Legs .	15	15	0
Ditto, with Tripod Stand and Silver Ring Compass . .	16	16	0
Ditto, fourteen-inch, with Round Legs and Card Compass	15	15	0
Ditto, ditto, with Silver Ring Compass and Tripod Stand .	17	17	0
Ditto, large size, complete	22	0	0
Standard Levelling Instrument	42	0	0
Plane Table, with Sights and Round Legs . .	6	16	6
Ditto, with Telescope, &c.	12	12	0
Cylindrical Cross Staff	0	16	0
Ditto, with Compass and Leg	2	12	6
Circumferenter, in Mahogany, without Legs . .	2	12	6
Ditto, ditto, larger size	4	4	0
Ditto, in Brass, with Round Legs from 4*l.* 14*s.* 6*d.* to	6	6	0
Ditto, ditto, with Ball and Socket Joint, and Round Legs .	6	16	6
Ditto, with Rack Motion, divided to 3 minutes, Ball and Socket Joint and Round Legs . . .	10	10	0
Ditto, ditto, with Levels and Levelling Plates . .	12	12	0
Best Brass Miners' Compass, with divided Cover, Ball and Socket Joint and Legs	7	17	6
Ditto, with Vertical Arc, Telescopic and Plain Sights, Levels in Compass, Rack Motion, &c., and Legs complete .	16	16	0
Prismatic Compass, plain	3	3	0
Ditto, with Azimuth Glasses	3	13	6
Ditto, three-and-a-half inch, plain	3	13	6
Ditto, ditto, with Azimuth Glasses	4	4	0
Prismatic Compass, three-and-a-half inch, with Silver Ring	5	5	0
[illegible] for Prismatic Compass, with Ball and Socket Joint	1	11	6
[illegible] Theodolite, with Telescope	14	14	0

	£	s.	d.
Box Sextant, Ordnance Pattern	5	5	0
Ditto, with Supplementary Arc	5	15	6
Ditto, with ditto, and Levels	6	6	0
Leather Case and Strap for Box Sextant	0	9	0
Metal Sextant, 4-inch Radius, divided on Silver to 20 seconds	10	10	0
Ditto, 5-inch ditto, to 20 seconds	13	13	0
Ditto, 6-inch ditto, to 20 seconds	14	14	0
Ditto, 7-inch ditto, to 10 seconds	16	16	0
Ditto, 8-inch ditto, with Double Frames, divided on Silver to 10 seconds	18	18	0
Ditto ditto, divided on Platina	21	0	0
Ditto ditto, divided on Gold	23	2	0
Dip Sector, as described in 'Treatise on Instruments,' by F. W. Simms	12	12	0
Troughton's Reflecting Circle	23	2	0
Six-inch Borda's Repeating Circle by Reflexion	21	0	0
Eight-inch ditto	23	2	0
Ten-inch ditto	25	0	0
Brass Counterpoise Stand for Circle or Sextant, in Mahogany Box	5	15	6
Glass Plane Artificial Horizons, two-and-a-quarter-inch diameter	1	11	6
Ditto, two-and-a-half-inch diameter	2	2	0
Ditto, three-inch diameter	3	3	0
Ditto, three-and-three-quarter inch	4	4	0
Ditto ditto, Ordnance Pattern	4	4	0
Best Mercurial Horizon, with Iron Bottle and Trough, Ordnance Pattern	5	5	0
Ditto ditto, smaller size	4	14	6
Ditto ditto, with Brass Folding-roof	5	5	0
Ditto ditto, with Ebony ditto	4	14	6
Ditto ditto, with Mahogany ditto	4	4	0
Marine Horizon (Captain Becher's)	5	5	0

LEVELS, THEODOLITES, &c.

Four-inch Pocket Level	0	9	6
Six-inch ditto	0	12	6
Eight-inch ditto	0	15	6
Ten-inch ditto	1	1	0
Twelve-inch ditto			

	£	s.	d.
Completely mounted, Equatorial, with Clock Movement, Micrometers, &c., 5 feet focus, three and three-quarter-inch Object Glass	200	0	0
Ditto ditto, 4-inch Object Glass	230	0	0
Ditto ditto, 8 feet focus, five-and-a-half-inch ditto	400	0	0
Ditto, 10 feet ditto, 6-inch ditto	600	0	0
Varley's Stand, Mahogany, with Brass Fittings, capable of carrying Telescopes from three-and-a-half to seven feet	12	12	0

MICROSCOPES, &c.

	£	s.	d.
Solar Microscopes . . from 6*l.* 16*s.* 6*d.* to	21	0	0
Botanic ditto, small size	0	15	0
Ditto, ditto	1	5	0
Compound ditto	2	12	6
Ditto ditto	2	15	0
Ditto ditto	3	10	0
Ditto ditto	4	10	0
Ditto ditto	5	10	0
Ditto ditto, larger, from 10*l.* 10*s.* upwards.			
Cloth Microscopes, Diagonal Print Machines, Black Mirrors, Claude Glasses, Magic Lanterns, &c.			

COMPASSES, SEXTANTS, QUADRANTS, &c.

	£	s.	d.
Binnacle Compasses . . . from 12*s.* to	0	18	0
Brass Hanging Compasses for Cabins . from 1*l.* 10*s.* to	5	0	0
ommon Azimuth Compass	4	14	6
Azimuth (Prismatic) Compass, large size, best construction, with Tripod Stand complete	16	16	0
itto ditto, smaller size	10	10	0
ocket Compasses in Wood, Brass, Metal Gilt, Silver and Gold . . . . from 3*s.* 6*d.* to	5	5	0
bony Quadrant with Tangent Screw	3	13	6
itto, with ditto and Telescope	4	14	6
itto ditto, best	5	15	6
bony Sextant, with Telescopes	8	8	0
itto, ditto, with Brass Arch, &c.	10	10	0
tical Square	1	1	0

	£	s.	d.
Military Case and Sling . . . from 10*s.* 6*d.* to	0	12	6
Portable Brass Stand for any of the above Telescopes, from 21*s.* to	2	12	6
Walking-Stick Telescope, Portable, with Compass . .	3	13	6
Ditto, without Compass	3	3	0
Ditto, in one length, with Compass	2	12	6
Ditto, without ditto	2	2	0
Dumpy Navy	4	4	0
Ditto, with Pancratic eye-piece	4	14	6
Two-feet Navy Telescope	2	12	6
Ditto ditto, Brass Body, covered with Leather . .	2	15	0
Ditto ditto, with Spray Shade	3	3	0
Three-feet ditto	5	5	0
Ditto ditto, with Spray Shade	5	15	6
Four-feet ditto, with Two Powers, in Case . .	12	12	0
Day or Night Telescope (Deck Glass)	4	4	0
Ditto ditto, with Spray Shade	4	14	6
Night Glass	3	3	0
Ditto, large size	4	4	0
Ordnance Signal Station Telescope	6	16	6
Thirty-inch Achromatic Telescope, two-and-a-quarter-inch Object Glass, mounted on Pillar-and-claw Stand, with a Terrestrial and an Astronomical Eye-piece, in a Mahogany Case	10	10	0
Ditto, with Vertical Rack Motion	12	12	0
Forty-five-inch Achromatic Telescope, two-and-three-quarter-inch Object Glass, on Brass Pillar-and-claw Stand, with a Terrestrial and an Astronomical Eye-piece, in a Mahogany Case	23	2	0
Ditto with Vertical Rack Motion, Finder, and extra Eye-pieces	26	5	0
Ditto, with Horizontal Rack, and Steadying Rods, complete	31	10	0
Ditto, three-and-a-quarter-inch Object Glass, with Rack-work Motions, Finder, one Terrestrial and three Astronomical Eye-pieces, in Mahogany Case	42	0	0
Ditto, three-and-three-quarter-inch Object Glass, mounted as above	68	5	0

Equatorial Stand, instead of Pillar-and-claw to the above Telescopes, constructed to any given Latitude, 30 Guineas extra

A CATALOGUE,

&c.

SPECTACLES AND OPERA GLASSES.

		£	s.	d.
Gold Spectacles, Single Joint	from 3*l.* 3*s.* to	5	5	0
Ditto, Double Joint	from 4*l.* 4*s.* to	6	6	0
Ditto, Hand Frames	from 4*l.* 4*s.* to	6	6	0
Silver Spectacles, Single Joint	from 10*s.* to	0	12	0
Ditto, Double Joint	from 13*s.* to	0	18	0
Ditto, Hand Frame		1	1	0
Tortoiseshell Spectacles, Single Joint		0	7	6
Ditto, Double Joint		0	12	6
Ditto, Hand Frame	from 7*s.* 6*d.* to	0	16	0
Fine Blue Steel Spectacles, Single Joint		0	10	6
Ditto, Double Joint		0	12	6
Eye Glasses, Gold Frame	from 1*l.* 1*s.* to	2	2	0
Ditto, Silver Frame	from 6*s.* to	0	8	0
Ditto, Shell Frame	from 4*s.* 6*d.* to	0	6	0
(*If with Brazilian Pebbles,* 8*s.* *per pair extra.*)				
Spectacle Cases	each	0	1	0
Opera Glasses, not Achromatic, in Plated Mountings	from 6*s.* to	1	11	6
Ditto, Achromatic, with Ivory Bodies and Gilt Mountings	from 2*l.* 2*s.* to	5	5	0

TELESCOPES.

		£	s.	d.
One-foot Achromatic (Camp) Telescope, having one Drawer		1	5	0
Ditto ditto, Portable, with Drawers		1	9	0
Ditto ditto, in Electrum		2	2	0
Ditto ditto, larger aperture in Brass		1	15	0
Eighteen-inch ditto		2	12	6
Two-feet ditto, Reconnoitering		3	13	6
Ditto ditto, in Electrum		5	5	0
Ditto ditto, in Electrum, with Compass, Agate Cap, Needle, &c.		6	6	0
Ditto ditto, ditto, with four Drawers in Brass		3	18	0
Thirty-inch ditto	ditto	5	5	0

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CATALOGUE

OF

INSTRUMENTS,

MADE BY

ROUGHTON AND SIMMS,

OPTICIANS,

AND

MATHEMATICAL INSTRUMENT MAKERS

TO THE

Honourable Board of Ordnance,

138, FLEET STREET,

TABLE XI.

Correction of Moon's Meridional Passage.

The application of this and the following Table is explained at page 80.

Long. in Time.	Argument—Daily Change of Mer. Passage.												
	40^{m}	42^{m}	44^{m}	46^{m}	48^{m}	50^{m}	52^{m}	54^{m}	56^{m}	58^{m}	60^{m}	62^{m}	64^{m}
h m	m	m	m	m	m	m	m	m	m	m	m	m	m
0. 0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1	1	1	1	1	1	1	1	1	1	1	1	1
40	1	1	1	1	1	1	1	1	1	2	2	2	2
1. 0	2	2	2	2	2	2	2	2	2	2	2	2	3
20	2	2	2	2	3	3	3	3	3	3	3	3	3
40	3	3	3	3	3	3	3	4	4	4	4	4	4
2. 0	3	3	4	4	4	4	4	4	4	5	5	5	5
20	4	4	4	4	5	5	5	5	5	5	6	6	6
40	4	4	5	5	5	5	6	6	6	6	6	7	7
3. 0	5	5	5	6	6	6	6	7	7	7	7	7	8
20	5	6	6	6	6	7	7	7	7	8	8	8	9
40	6	6	7	7	7	7	8	8	8	9	9	9	9
4. 0	6	7	7	7	8	8	8	9	9	9	10	10	10
20	7	7	8	8	8	9	9	9	10	10	10	11	11
40	7	8	8	9	9	9	10	10	10	11	11	12	12
5. 0	8	9	9	9	10	10	10	11	11	12	12	12	13
20	9	9	9	10	10	11	11	12	12	12	13	13	14
40	9	10	10	11	11	11	12	12	13	13	14	14	14
6. 0	10	10	11	11	12	12	13	13	13	14	14	15	15
20	10	11	11	12	12	13	13	14	14	15	15	16	16
40	11	11	12	12	13	13	14	14	15	15	16	17	17
7. 0	11	12	12	13	14	14	15	15	16	16	17	17	18
20	12	12	13	14	14	15	15	16	16	17	18	18	19
40	12	13	14	14	15	15	16	17	17	18	18	19	20
8. 0	13	14	14	15	15	16	17	17	18	19	19	20	20
20	13	14	15	15	16	17	17	18	19	19	20	21	21
40	14	15	15	16	17	17	18	19	19	20	21	21	22
9. 0	14	15	16	17	17	18	19	20	20	21	22	22	23
20	15	16	17	17	18	19	20	20	21	22	22	23	21
40	15	16	17	18	19	19	20	21	22	22	23	24	25
10. 0	16	17	18	19	19	20	21	22	22	23	24	25	26
20	16	18	18	19	20	21	22	22	23	24	25	26	26
40	17	18	19	20	21	21	22	23	24	25	26	26	27
11. 0	17	19	20	20	21	22	23	24	25	26	26	27	28
20	18	19	20	21	22	23	24	25	25	26	27	28	29
40	18	20	21	22	23	23	24	25	26	27	28	29	30
12. 0	19	20	21	22	23	24	25	26	27	28	29	30	31

TABLE XII.

Effect of a Change of 1° in Declination on the Moon's Semidiameter (as given in the Naut. Alm.)

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	40ᵐ	42ᵐ	44ᵐ	46ᵐ	48ᵐ	50ᵐ	52ᵐ	54ᵐ	56ᵐ	58ᵐ	60ᵐ	62ᵐ	64ᵐ	66
h m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
0. 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1
40	1	1	1	1	1	1	1	1	1	2	2	2	2	2
1. 0	2	2	2	2	2	2	2	2	2	2	2	2	3	3
20	2	2	2	2	3	3	3	3	3	3	3	3	3	4
40	3	3	3	3	3	3	3	4	4	4	4	4	4	[illegible]
2. 0	3	3	4	4	4	4	4	4	4	5	5	5	5	[illegible]
20	4	4	4	4	5	5	5	5	5	5	6	6	6	[illegible]
40	4	4	5	5	5	5	6	6	6	6	6	7	7	[illegible]
3. 0	5	5	5	6	6	6	6	7	7	7	7	7	8	[illegible]
20	5	6	6	6	6	7	7	7	7	8	8	8	9	[illegible]
40	6	6	7	7	7	7	8	8	8	9	9	9	9	[illegible]
4. 0	6	7	7	7	8	8	8	9	9	9	10	10	10	[illegible]
20	7	7	8	8	8	9	9	9	10	10	10	11	11	[illegible]
40	7	8	8	9	9	9	10	10	10	11	11	12	12	[illegible]
5. 0	8	9	9	9	10	10	10	11	11	12	12	12	13	[illegible]
20	9	9	9	10	10	11	11	12	12	12	13	13	14	[illegible]
40	9	10	10	11	11	11	12	12	13	13	14	14	14	[illegible]
6. 0	10	10	11	11	12	12	13	13	13	14	14	15	15	[illegible]
20	10	11	11	12	12	13	13	14	14	15	15	16	16	[illegible]
40	11	11	12	12	13	13	14	14	15	15	16	17	17	[illegible]
7. 0	11	12	12	13	14	14	15	15	16	16	17	17	18	[illegible]
20	12	12	13	14	14	15	15	16	16	17	18	18	19	[illegible]
40	12	13	14	14	15	15	16	17	17	18	18	19	20	[illegible]
8. 0	13	14	14	15	15	16	17	17	18	19	19	20	20	[illegible]
20	13	14	15	15	16	17	17	18	19	19	20	21	21	[illegible]
40	14	15	15	16	17	17	18	19	19	20	21	21	22	[illegible]
9. 0	14	15	16	17	17	18	19	20	20	21	22	22	23	[illegible]
20	15	16	17	17	18	19	20	20	21	22	22	23	21	[illegible]
40	15	16	17	18	19	19	20	21	22	22	23	24	25	[illegible]
10. 0	16	17	18	19	19	20	21	22	22	23	24	25	26	[illegible]
20	16	18	18	19	20	21	22	22	23	24	25	26	26	[illegible]
40	17	18	19	20	21	21	22	23	24	25	26	26	27	[illegible]
11. 0	17	19	20	20	21	22	23	24	25	26	26	27	28	[illegible]
20	18	19	20	21	22	23	24	25	25	26	27	28	29	[illegible]
40	18	20	21	22	23	23	24	25	26	27	28	29	30	[illegible]
12. 0	19	20	21	22	23	24	25	26	27	28	29	30	31	[illegible]

TABLE XII.

Effect of a Change of 1° in Declination on the Moon's Semidiameter (as given in the Naut. Alm.)

Dec.	Corr.	Dec.

TABLE VIII.

Showing the Length of a Second of Longitude and Latitude in English Feet, on the Earth's Surface.

Compression = $\frac{1}{300}$

Computed by Mr. Baily's Formula XLIII.

Lat.	Second of Long.	Second of Lat.	Lat.	Second of Long.	Second of Lat.
°	Ft.	Ft.	°	Ft.	Ft.
0	101.42	101.42	35	83.17	101.75
1	101.40		36	82.15	
2	101.36		37	81.10	
3	101.28		38	80.02	
4	101.17		39	78.92	
5	101.03	101.43	40	77.80	101.84
6	100.87		41	76.65	
7	100.67		42	75.48	
8	100.44		43	74.29	
9	100.18		44	73.07	
10	99.89	101.45	45	71.83	101.93
11	99.57		46	70.57	
12	99.22		47	69.29	
13	98.84		48	67.99	
14	98.43		49	66.66	
15	97.99	101.49	50	65.32	102.02
16	97.52		51	63.95	
17	97.02		52	62.57	
18	96.49		53	61.17	
19	95.44		54	59.75	
20	95.36	101.54	55	58.30	102.11
21	94.74		56	56.84	
22	94.09		57	55.37	
23	93.41		58	53.87	
24	92.70		59	52.36	
25	91.97	101.60	60	50.84	102.19
26	91.21		61	49.30	
27	90.43		62	47.74	
28	89.62		63	46.17	
29	88.77		64	44.58	
30	87.90	101.67	65	42.98	102.26
31	87.01		66	41.37	
32	86.09		67	39.74	
33	85.14		68	38.10	
34	84.17		69	36.45	

" If the equatorial diameter of the earth be assumed equal to 7924 miles, a degree of longitude at the equator will be equal to 69.15 miles = 365110 feet; and

TABLE IX.

Reduction in Links and Decimals upon each Chain's Length, for the following Angles of Elevation and Depression.

Angle.	Reductn	Angle.	Reductn	Angle.	Reductn
3°. 0	0.14	9°. 0	1.24	15°. 0	3.40
		30	1.38	30	3.64
4°. 0	0.25	10°. 0	1.52	16°. 0	3.88
		30	1.68	30	4.12
5°. 0	0.38	11°. 0	1.84	17°. 0	4.37
		30	2.01	30	4.63
6°. 0	0.55	12°. 0	2.19	18°. 0	4.90
30	0.65	30	2.37	30	5.17
7°. 0	0.75	13°. 0	2.56	19°. 0	5.44
30	0.86	30	2.77	30	5.74
8°. 0	0.98	14°. 0	2.97	20°. 0	6.03
30	1.10	30	3.18	30	6.33

The reduction for one chain (from the above Table) multiplied by the number of chains, will give the quantity to be subtracted from the measured length of an inclination, to reduce it to horizontal measure.

TABLE X.

Shewing the Rate of Inclination of Inclined Planes, for the following Angles of Elevation.

Angle.	One in	Angle.	One in	Angle.	One in
0°15′	228	3°30′	17	7° 0′	8
0.30	114	3.45	16	7.30	7¼
0.45	76	4. 0	15	8. 0	7
1. 0	56	4.15	14	9. 0	6½
1.15	46	4.30	13	10. 0	6
1.30	38	4.45	12	11. 0	5¾
1.45	32	5. 0	11½	12. 0	5½

TABLE VII.

Reduction to the Meridian.

Argument = the Hour Angle from the Meridian.

s	15m	16m	17m	18m	19m	20m	21m	22m	23m
0	2141	2436	2750	3083	3434	3805	4195	4604	5031
1	2146	2441	2755	3088	3441	3812	4202	4611	5039
2	2151	2446	2761	3093	3447	3818	4208	4618	5046
3	2155	2451	2766	3099	3453	3824	4215	4625	5053
4	2160	2456	2771	3106	3459	3831	4222	4632	5061
5	2165	2461	2777	3111	3465	3837	4228	4639	5068
6	2170	2466	2782	3117	3471	3843	4235	4646	5075
7	2175	2472	2788	3123	3477	3850	4242	4653	5083
8	2179	2477	2793	3128	3483	3856	4248	4660	5090
9	2184	2482	2799	3134	3489	3863	4255	4667	5097
10	2189	2487	2804	3140	3495	3869	4262	4674	5105
11	2194	2492	2809	3146	3501	3875	4269	4681	5112
12	2198	2497	2815	3151	3507	3882	4275	4688	5119
13	2203	2502	2820	3157	3513	3888	4282	4695	5127
14	2208	2507	2826	3163	3519	3895	4289	4702	5134
15	2213	2513	2831	3169	3525	3901	4295	4709	5141
16	2218	2518	2837	3175	3531	3907	4302	4716	5149
17	2223	2523	2842	3180	3538	3914	4309	4723	5156
18	2227	2528	2848	3186	3544	3920	4316	4730	5163
19	2232	2533	2853	3192	3550	3927	4322	4737	5171
20	2237	2538	2859	3198	3556	3933	4329	4744	5178
21	2242	2544	2864	3204	3562	3940	4336	4751	5186
22	2247	2549	2870	3209	3568	3946	4343	4758	5193
23	2252	2554	2875	3215	3574	3952	4350	4766	5200
24	2257	2559	2881	3221	3581	3959	4356	4773	5208
25	2262	2564	2886	3227	3587	3965	4363	4780	5215
26	2266	2570	2892	3233	3593	3972	4370	4787	5223
27	2272	2575	2897	3239	3599	3978	4377	4794	5230
28	2276	2580	2903	3244	3605	3985	4383	4801	5237
29	2281	2585	2908	3250	3611	3991	4390	4808	5245
30	2286	2590	2914	3256	3618	3998	4397	4815	5252
31	2291	2596	2919	3262	3624	4004	4404	4822	5260
32	2296	2601	2925	3268	3630	4011	4411	4829	5267
33	2301	2606	2930	3274	3636	4017	4418	4837	5275
34	2306	2611	2936	3280	3642	4024	4424	4844	5282
35	2311	2617	2942	3286	3648	4030	4431	4851	5290
36	2316	2622	2947	3291	3655	4037	4438	4858	5297
37	2321	2627	2952	3297	3661	4043	4445	4865	5305
38	2326	2632	2958	3303	3667	4050	4452	4872	5312
39	2331	2638	2964	3309	3673	4056	4459	4880	5320
40	2335	2643	2970	3315	3680	4063	4465	4887	5327
41	2540	2648	2975	3321	3686	4070	4472	4894	5335
42	2345	2654	2981	3327	3692	4076	4479	4901	5342
43	2350	2659	2986	3333	3698	4083	4486	4908	5350
44	2355	2664	2992	3339	3705	4089	4493	4916	5357
45	2360	2669	2998	3345	3711	4096	4500	4923	5365
46	2365	2675	3003	3351	3717	4102	4507	4930	5372
47	2370	2680	3009	3357	3723	4109	4514	4937	5380
48	2375	2685	3015	3363	3730	4116	4520	4944	5387
49	2380	2690	3020	3369	3736	4122	4527	4952	5395
50	2385	2696	3026	3375	3742	4129	4534	4959	5402
51	2390	2701	3031	3380	3749	4135	4541	4966	5410

TABLE VII.

Reduction to the Meridian.

Argument = the Hour Angle from the Meridian.

0m	1m	2m	3m	4m	5m	6m	7m	8m	9m	10m	11m	12m	13m	14m
0	9	38	86	152	238	343	466	609	771	952	1152	1370	1608	1865
0	10	39	87	153	240	345	469	612	774	955	1155	1374	1612	1870
0	10	39	88	155	241	346	471	614	777	958	1159	1378	1617	1874
0	10	40	89	156	243	348	473	617	780	961	1162	1382	1621	1879
0	11	41	90	157	244	350	475	619	782	964	1166	1386	1625	1883
0	11	41	91	159	246	352	478	622	785	968	1169	1390	1629	1887
0	12	42	92	160	248	354	480	624	788	971	1173	1393	1633	1892
0	12	43	93	161	249	356	482	627	791	974	1176	1397	1637	1896
0	12	43	93	163	251	358	484	630	794	977	1180	1401	1641	1901
0	13	44	94	164	253	360	487	632	797	981	1183	1405	1646	1905
0	13	45	95	165	254	362	489	635	800	984	1187	1409	1650	1910
0	13	45	96	167	256	364	491	637	803	987	1190	1413	1654	1914
0	14	46	97	168	257	366	493	640	806	990	1194	1416	1658	1919
0	14	47	98	169	259	368	496	643	809	993	1197	1420	1662	1923
1	14	47	99	171	261	370	498	645	811	997	1201	1424	1667	1928
1	15	48	100	172	262	372	500	648	814	1000	1205	1428	1671	1932
1	15	49	102	173	264	374	503	650	817	1003	1208	1432	1675	1937
1	16	50	103	175	266	376	505	653	820	1006	1212	1436	1679	1941
1	16	50	104	176	267	378	507	656	823	1010	1215	1440	1683	1946
1	17	51	105	177	269	380	510	658	826	1013	1219	1444	1688	1950
1	17	52	106	179	271	382	512	661	829	1016	1222	1448	1692	1955
1	17	53	107	180	272	384	514	664	832	1020	1226	1451	1696	1960
1	18	53	108	182	274	386	517	666	835	1023	1230	1455	1700	1964
1	18	54	109	183	276	388	519	669	838	1026	1233	1459	1705	1968
2	19	55	110	184	278	390	521	672	841	1029	1237	1463	1709	1973
2	19	56	111	185	279	392	524	674	844	1033	1241	1467	1713	1978
2	20	56	112	187	281	394	526	677	847	1036	1244	1471	1717	1982
2	20	57	113	188	283	396	528	680	850	1039	1248	1475	1722	1987
2	20	58	114	190	284	398	531	682	853	1043	1251	1479	1726	1992
2	21	59	116	191	286	400	533	685	856	1046	1255	1483	1730	1997
3	21	59	117	193	288	402	535	688	859	1049	1259	1487	1734	2001
3	22	60	118	194	289	404	538	690	862	1053	1262	1491	1739	2005
3	22	61	119	196	291	406	540	693	865	1056	1266	1495	1743	2010
3	23	62	120	197	293	408	543	696	868	1059	1270	1499	1747	2014
3	23	63	121	198	295	410	545	699	871	1062	1273	1503	1751	2019
3	24	64	122	200	297	412	547	701	874	1066	1277	1507	1756	2024
3	24	64	123	201	299	415	550	704	877	1069	1281	1511	1760	2028
4	25	65	124	203	300	417	552	707	880	1073	1284	1515	1764	2033
4	25	66	126	204	302	419	555	709	883	1076	1288	1519	1769	2038
4	26	67	127	206	304	421	557	712	886	1079	1292	1523	1773	2042
4	26	68	128	207	306	423	559	715	889	1083	1295	1527	1777	2047
4	27	68	129	209	307	425	562	718	892	1086	1299	1531	1782	2052
5	28	69	130	210	309	427	564	720	896	1090	1303	1535	1786	2056
5	28	70	131	212	311	429	567	723	899	1093	1307	1539	1790	2061
5	29	71	133	213	313	432	569	726	902	1096	1310	1543	1795	2066
5	29	72	134	215	315	434	572	729	905	1100	1314	1547	1799	2070
6	30	73	135	216	316	436	574	732	908	1103	1318	1551	1804	2075
6	30	74	136	218	318	438	577	734	911	1107	1321	1555	1808	2080
6	31	75	137	219	320	440	579	737	914	1110	1325	1559	1812	2084
6	31	75	139	221	322	442	582	740	917	1114	1329	1563	1817	2089
7	32	76	140	222	324	444	584	743	920	1117	1333	1567	1821	2094
7	33	77	141	225	326	447	587	745	923	1120	1336	1571	1825	2099
7	33	78	142	226	328	449	589	748	927	1124	1340	1575	1830	2103

TABLE V.

Logarithms to compute the Longitude from the Difference between the Interv
of the Transit of the Moon's bright Limb and a Star.

2 Min. s	Log.	Parts	2 Min. s	Log.	Parts	2 Min. s	Log.	Parts	2 Min. s	Log.
30 ·0	1 ·362966	0	34 ·0	1 ·351035	0	38 ·0	1 ·339396	0	42 ·0	1 ·328034
·1	1 ·362664	30	·1	1 ·350740	29	·1	1 ·339109	29	·1	1 ·327753
·2	1 ·362362	60	·2	1 ·350446	59	·2	1 ·338821	57	·2	1 ·327473
·3	1 ·362061	90	·3	1 ·350152	88	·3	1 ·338534	86	·3	1 ·327192
·4	1 ·361759	120	·4	1 ·349858	118	·4	1 ·338248	115	·4	1 ·326912
·5	1 ·361458	150	·5	1 ·349564	147	·5	1 ·337961	143	·5	1 ·326632
·6	1 ·361157	181	·6	1 ·349271	176	·6	1 ·337675	172	·6	1 ·326352
·7	1 ·360856	211	·7	1 ·348977	206	·7	1 ·337388	201	·7	1 ·326073
·8	1 ·360556	241	·8	1 ·348684	235	·8	1 ·337102	230	·8	1 ·325793
·9	1 ·360255	271	·9	1 ·348391	265	·9	1 ·336816	258	·9	1 ·325514
31 ·0	1 ·359955	0	35 ·0	1 ·348098	0	39 ·0	1 ·336530	0	43 ·0	1 ·325235
·1	1 ·359655	30	·1	1 ·347805	29	·1	1 ·336244	28	·1	1 ·324956
·2	1 ·359355	60	·2	1 ·347513	58	·2	1 ·335959	57	·2	1 ·324677
·3	1 ·359055	90	·3	1 ·347220	88	·3	1 ·335674	85	·3	1 ·324399
·4	1 ·358756	120	·4	1 ·346928	117	·4	1 ·335389	114	·4	1 ·324120
·5	1 ·358457	149	·5	1 ·346636	146	·5	1 ·335104	142	·5	1 ·323842
·6	1 358157	179	·6	1 ·346344	175	·6	1 ·334819	171	·6	1 ·323564
·7	1 ·357859	209	·7	1 ·346053	204	·7	1 ·334534	199	·7	1 ·323286
·8	1 ·357560	239	·8	1 ·345761	234	·8	1 ·334250	228	·8	1 ·323008
·9	1 ·357261	269	·9	1 ·345470	263	·9	1 ·333966	256	·9	1 ·322730
32 ·0	1 ·356963	0	36 ·0	1 ·345179	0	40 ·0	1 ·333682	0	44 ·0	1 ·322453
·1	1 ·356665	30	·1	1 ·344888	29	·1	1 ·333398	28	·1	1 ·322176
·2	1 ·356367	59	·2	1 ·344598	58	·2	1 ·333114	57	·2	1 ·321898
·3	1 ·356069	89	·3	1 ·344307	87	·3	1 ·332831	85	·3	1 ·321621
·4	1 ·355772	119	·4	1 ·344017	116	·4	1 ·332547	113	·4	1 ·321345
·5	1 ·355474	148	·5	1 ·343727	145	·5	1 ·332264	141	·5	1 ·321068
·6	1 ·355177	178	·6	1 ·343437	174	·6	1 ·331981	170	·6	1 ·320791
·7	1 ·354880	208	·7	1 ·343147	203	·7	1 ·331698	198	·7	1 ·320515
·8	1 ·354583	238	·8	1 ·342858	232	·8	1 ·331415	226	·8	1 ·320239
·9	1 ·354286	267	·9	1 ·342568	261	·9	1 ·331132	255	·9	1 ·319963
33 0	1 ·353990	0	37 ·0	1 ·342279	0	41 ·0	1 ·330850	0	45 ·0	1 ·319687
·1	1 ·353694	29	·1	1 ·341990	29	·1	1 ·330568	28	·1	1 ·319411
·2	1 ·353397	59	·2	1 ·341701	58	·2	1 ·330285	56	·2	1 ·319136
·3	1 ·353102	88	·3	1 ·341412	86	·3	1 ·330003	84	·3	1 ·318860
·4	1 ·352806	118	·4	1 ·341124	115	·4	1 ·329722	112	·4	1 ·318585
·5	1 ·352510	147	·5	1 ·340835	144	·5	1 ·329440	140	·5	1 ·318310
·6	1 ·352215	177	·6	1 ·340547	173	·6	1 ·329158	169	·6	1 ·318035
·7	1 ·351920	206	·7	1 ·340259	202	·7	1 ·328877	197	·7	1 ·317760
·8	1 ·351624	236	·8	1 ·339671	230	·8	1 ·328596	225	·8	1 ·317486
·9	1 ·351330	265	·9	1 ·339683	259	·9	1 ·328315	253	·9	1 ·317211

TABLE VI.

Effect of a Change in the Moon's Semidiameter on the Time of its passing the Meridian.

Change of ☽'s Semidiam.	Moon's Declination.				
	0°	8°	16°	22°	28°
"	s	s	s	s	s
1	·07	·07	·07	·07	·07
2	·14	·14	·14	·15	·15

TABLE V.

Logarithms to compute the Longitude from the Difference between the Intervals of the Transit of the Moon's bright Limb and a Star.

2 Min s	Log.	Parts	2 Min. s	Log.	Parts	2 Min. s	Log.	Parts	2 Min. s	Log.	Parts
6·0	1·441689	0	12·0	1·420737	0	18·0	1·400682	0	24·0	1·381448	0
·1	1·441332	36	·1	1·420396	34	·1	1·400355	33	·1	1·381134	31
·2	1·440975	71	·2	1·420055	68	·2	1·400028	65	·2	1·380820	63
·3	1·440619	107	·3	1·419715	102	·3	1·399701	98	·3	1·380506	94
·4	1·440263	142	·4	1·419373	136	·4	1·399375	130	·4	1·380193	125
·5	1·439907	178	·5	1·419033	170	·5	1·399049	163	·5	1·379880	156
·6	1·439551	214	·6	1·418693	204	·6	1·398723	196	·6	1·379567	188
·7	1·439196	249	·7	1·418354	238	·7	1·398397	228	·7	1·379254	219
·8	1·438840	285	·8	1·418014	272	·8	1·398071	261	·8	1·378941	250
·9	1·438486	320	·9	1·417674	306	·9	1·397746	293	·9	1·378629	282
7·0	1·438131	0	13·0	1·417335	0	19·0	1·397421	0	25·0	1·378317	0
·1	1·437777	35	·1	1·416996	34	·1	1·397096	32	·1	1·378005	31
·2	1·437423	71	·2	1·416657	67	·2	1·396772	65	·2	1·377693	62
·3	1·437069	106	·3	1·416319	101	·3	1·396447	97	·3	1·377382	93
·4	1·436715	141	·4	1·415981	135	·4	1·396123	129	·4	1·377071	124
·5	1·436362	177	·5	1·415643	168	·5	1·395799	161	·5	1·376759	155
·6	1·436009	212	·6	1·415306	202	·6	1·395476	194	·6	1·376449	186
·7	1·435650	247	·7	1·414969	236	·7	1·395152	226	·7	1·376138	218
·8	1·435304	282	·8	1·414631	276	·8	1·394829	258	·8	1·375827	249
·9	1·434952	318	·9	1·414294	303	·9	1·394506	291	·9	1·375517	280
8·0	1·434600	0	14·0	1·413957	0	20·0	1·394183	0	26·0	1·375207	0
·1	1·434248	35	·1	1·413621	33	·1	1·393860	32	·1	1·374897	31
·2	1·433897	70	·2	1·413285	67	·2	1·393538	64	·2	1·374587	62
·3	1·433546	105	·3	1·412949	100	·3	1·393216	96	·3	1·374278	92
·4	1·433195	140	·4	1·412613	134	·4	1·392894	128	·4	1·373969	123
·5	1·432845	175	·5	1·412278	167	·5	1·392572	160	·5	1·373659	154
·6	1·432494	210	·6	1·411942	201	·6	1·392251	193	·6	1·373351	185
·7	1·432144	245	·7	1·411607	234	·7	1·391930	225	·7	1·373042	216
·8	1·431795	280	·8	1·411273	268	·8	1·391608	257	·8	1·372733	246
·9	1·431445	315	·9	1·410938	301	·9	1·391288	289	·9	1·372425	277
9·0	1·431096	0	15·0	1·410604	0	21·0	1·390967	0	27·0	1·372117	0
·1	1·430747	35	·1	1·410270	33	·1	1·390647	32	·1	1·371809	31
·2	1·430398	70	·2	1·409936	67	·2	1·390327	64	·2	1·371501	61
·3	1·430050	104	·3	1·409602	100	·3	1·390007	96	·3	1·371194	92
·4	1·429701	139	·4	1·409269	133	·4	1·389687	128	·4	1·370887	122
·5	1·429354	174	·5	1·408935	166	·5	1·389367	159	·5	1·370579	153
·6	1·429006	209	·6	1·408602	200	·6	1·389048	191	·6	1·370273	184
·7	1·428659	244	·7	1·408270	233	·7	1·388729	223	·7	1·369966	214
·8	1·428312	278	·8	1·407937	266	·8	1·388410	255	·8	1·369659	245
·9	1·427965	313	·9	1·407605	300	·9	1·388091	287	·9	1·369353	275
10·0	1·427618	0	16·0	1·407273	0	22·0	1·387773	0	28·0	1·369047	0
·1	1·427272	35	·1	1·406941	33	·1	1·387454	32	·1	1·368741	30
·2	1·426925	69	·2	1·406610	66	·2	1·387137	63	·2	1·368435	61
·3	1·426580	103	·3	1·406278	99	·3	1·386819	95	·3	1·368130	91
·4	1·426234	138	·4	1·405947	132	·4	1·386501	127	·4	1·367825	122
·5	1·425888	172	·5	1·405617	165	·5	1·386183	158	·5	1·367520	152
·6	1·425543	207	·6	1·405286	198	·6	1·385867	190	·6	1·367215	183
·7	1·425198	242	·7	1·404956	231	·7	1·385550	222	·7	1·366910	213
·8	1·424854	276	·8	1·404626	264	·8	1·385233	254	·8	1·366605	244
·9	1·424509	310	·9	1·404296	297	·9	1·384916	285	·9	1·366301	274
11·0	1·424165	0	17·0	1·403966	0	23·0	1·384600	0	29·0	1·365997	0
·1	1·423821	34	·1	1·403636	33	·1	1·384284	31	·1	1·365693	30

TABLE V.

Logarithms to compute the Longitude from the Difference between the Intervals of the Transit of the Moon's bright Limb and a Star.

1 Min. s	Log.	Parts	1 Min. s	Log.	Parts	1 Min. s	Log.	Parts	2 Min. s	Log.	Parts
42 ·0	1 ·536442	0	48 ·0	1 ·510875	0	54 ·0	1 ·486648	0	0 ·0	1 ·463627	0
·1	1 ·536004	43	·1	1 ·510461	41	·1	1 ·486255	39	·1	1 ·463253	37
·2	1 ·535566	87	·2	1 ·510047	82	·2	1 ·485862	78	·2	1 ·462879	75
·3	1 ·535130	130	·3	1 ·509633	123	·3	1 ·485469	118	·3	1 ·462505	112
·4	1 ·534693	174	·4	1 ·509220	165	·4	1 ·485077	157	·4	1 ·462132	149
·5	1 ·534256	217	·5	1 ·508808	206	·5	1 ·484685	196	·5	1 ·461759	187
·6	1 ·533821	261	·6	1 ·508395	247	·6	1 ·484294	235	·6	1 ·461386	224
·7	1 ·533385	304	·7	1 ·507983	288	·7	1 ·483903	274	·7	1 ·461014	261
·8	1 ·532950	348	·8	1 ·507571	330	·8	1 ·483512	313	·8	1 ·460642	298
·9	1 ·532515	391	·9	1 ·507161	371	·9	1 ·483121	353	·9	1 ·460270	336
43 ·0	1 ·532081	0	49 ·0	1 ·506749	0	55 ·0	1 ·482731	0	1 ·0	1 ·459898	0
·1	1 ·531647	43	·1	1 ·506337	41	·1	1 ·482341	39	·1	1 ·459527	37
·2	1 ·531214	86	·2	1 ·505928	82	·2	1 ·481952	78	·2	1 ·459156	74

TABLE III.

For converting Intervals of Sidereal into corresponding Intervals of Mean Solar Time.

Hours.			Minutes.						Seconds.					
h	m	s	m	s	m	s	m	s	s	s	s	s	s	s
1	0	9,830	1	0,164	21	3,440	41	6,717	1	0,003	21	0,057	41	0,112
2	0	19,659	2	0,328	22	3,604	42	6,881	2	0,005	22	0,060	42	0,115
3	0	29,489	3	0,491	23	3,768	43	7,044	3	0,008	23	0,063	43	0,118
4	0	39,318	4	0,655	24	3,932	44	7,208	4	0,011	24	0,066	44	0,120
5	0	49,148	5	0,819	25	4,096	45	7,372	5	0,014	25	0,068	45	0,123
6	0	58,977	6	0,983	26	4,259	46	7,536	6	0,016	26	0,071	46	0,126
7	1	8,807	7	1,147	27	4,423	47	7,700	7	0,019	27	0,074	47	0,128
8	1	18,636	8	1,311	28	4,587	48	7,864	8	0,022	28	0,076	48	0,131
9	1	28,466	9	1,474	29	4,751	49	8,027	9	0,025	29	0,079	49	0,134
10	1	38,296	10	1,638	30	4,915	50	8,191	10	0,027	30	0,082	50	0,137
11	1	48,125	11	1,802	31	5,079	51	8,355	11	0,030	31	0,085	51	0,140
12	1	57,955	12	1,966	32	5,242	52	8,519	12	0,033	32	0,087	52	0,142
13	2	7,784	13	2,130	33	5,406	53	8,683	13	0,036	33	0,090	53	0,145
14	2	17,614	14	2,294	34	5,570	54	8,847	14	0,038	34	0,093	54	0,148
15	2	27,443	15	2,457	35	5,734	55	9,010	15	0,041	35	0,096	55	0,150
16	2	37,273	16	2,621	36	5,898	56	9,174	16	0,044	36	0,098	56	0,153
17	2	47,103	17	2,785	37	6,062	57	9,338	17	0,047	37	0,101	57	0,156
18	2	56,932	18	2,949	38	6,225	58	9,502	18	0,049	38	0,104	58	0,159
19	3	6,762	19	3,113	39	6,389	59	9,666	19	0,052	39	0,106	59	0,161
20	3	16,591	20	3,277	40	6,553	60	9,830	20	0,055	40	0,109	60	0,164
21	3	26,421												
22	3	36,250												
23	3	46,080												
24	3	55,909												

The quantities taken from this Table must be subtracted from a sidereal interval, to obtain the corresponding interval in mean solar time.

TABLE IV.

For converting Intervals of Mean Solar into corresponding Intervals of Sidereal Time.

Hours.			Minutes.						Seconds.					
h	m	s	m	s	m	s	m	s	s	s	s	s	s	s
1	0	9,856	1	0,164	21	3,450	41	6,735	1	0,003	21	0,057	41	0,112
2	0	19,713	2	0,329	22	3,614	42	6,900	2	0,005	22	0,060	42	0,115
3	0	29,569	3	0,493	23	3,778	43	7,064	3	0,008	23	0,063	43	0,118
4	0	39,426	4	0,657	24	3,943	44	7,228	4	0,011	24	0,066	44	0,120
5	0	49,282	5	0,821	25	4,107	45	7,392	5	0,014	25	0,068	45	0,123
6	0	59,139	6	0,986	26	4,271	46	7,557	6	0,016	26	0,071	46	0,126
7	1	8,995	7	1,150	27	4,436	47	7,721	7	0,019	27	0,074	47	0,128
8	1	18,852	8	1,314	28	4,600	48	7,885	8	0,022	28	0,076	48	0,131
9	1	28,708	9	1,478	29	4,764	49	8,050	9	0,025	29	0,079	49	0,134
10	1	38,565	10	1,643	30	4,928	50	8,214	10	0,027	30	0,082	50	0,137
11	1	48,421	11	1,807	31	5,092	51	8,378	11	0,030	31	0,085	51	0,140
12	1	58,278	12	1,971	32	5,257	52	8,542	12	0,033	32	0,087	52	0,142
13	2	8,134	13	2,136	33	5,421	53	8,707	13	0,036	33	0,090	53	0,145
14	2	17,991	14	2,300	34	5,585	54	8,871	14	0,038	34	0,093	54	0,148
15	2	27,847	15	2,464	35	5,750	55	9,035	15	0,041	35	0,096	55	0,150
16	2	37,704	16	2,628	36	5,914	56	9,199	16	0,044	36	0,098	56	0,153
17	2	47,560	17	2,793	37	6,078	57	9,364	17	0,047	37	0,101	57	0,156

TABLE II.

For determining Altitudes with the Barometer.

Computed by Mr. Baily's Formula XXXVIII.

Thermometers in open Air.						Thermometers to the Barometer		Latitude of the Place.	
S	A	S	A	S	A	D	B	L	C
°		°		°		°		°	
40	4 ·76891	84	4 ·79019	128	4 ·81048	0	0 ·00000	0	0 ·00117
41	·76940	85	·79066	129	·81093	1	·00004	3	·00116
42	·76989	86	·79113	130	·81138	2	·00009	6	·00114
43	·77039	87	·79160	131	·81183	3	·00013	9	·00111
44	·77089	88	·79207	132	·81228	4	·00017	12	·00107
45	4 ·77138	89	4 ·79254	133	4 ·81272	5	0 ·00022	15	0 ·00101
46	·77187	90	·79301	134	·81317	6	·00026	18	·00095
47	·77236	91	·79348	135	·81362	7	·00030	21	·00087
48	·77286	92	·79395	136	·81407	8	·00035	24	·00078

TABLE I.

To reduce the Apparent to the True Level.

Argument = the Distance in Feet.

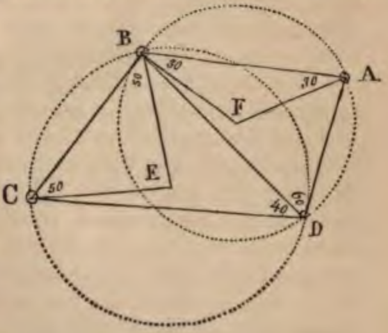
Dist. in Feet.	Correctⁿ in Decimals of a Foot.	Dist. in Feet.	Correctⁿ in Decimals of a Foot.	Dist. in Feet.	Correctⁿ in Decimals of a Foot.	Dist. in Feet.	Correctⁿ in Decimals of a Foot.	Dist. in Feet.	Correctⁿ in Decimals of a Foot.
20	0·00001	1020	0·02489	2020	0·09762	3020	0·21821	4020	0·38665
40	·00004	40	·02588	40	·09957	40	·22111	40	·39050
60	·00009	60	·02688	60	·10153	60	·22403	60	·39439
80	·00015	80	·02791	80	·10351	80	·22697	80	·39828
100	0·00024	1100	0·02895	2100	0·10551	3100	0·22993	4100	0·40218
20	·00034	20	·03001	20	·10753	20	·23290	20	·40613
40	·00047	40	·03109	40	·10956	40	·23590	40	·41008
60	·00061	60	·03219	60	·11162	60	·23892	60	·41404
80	·00077	80	·03331	80	·11370	80	·24195	80	·41805
200	0·00096	1200	0·03445	2200	0·11580	3200	0·24500	4200	0 42205
20	·00116	20	·03561	20	·11792	20	·24807	20	·42607
40	·00138	40	·03679	40	·12005	40	·25117	40	·43014
60	·00162	60	·03798	60	·12220	60	·25427	60	·43420
80	00187	80	·03920	80	·12437	80	·25740	80	·43827
300	0·00215	1300	0·04043	2300	0·12657	3300	0·26055	4300	0·44239
20	·00245	20	·04169	20	·12878	20	·26372	20	·44650
40	·00276	40	·04296	40	·13101	40	·26691	40	·45066
60	·00310	60	·04425	60	·13326	60	·27011	60	·45483
80	·00345	80	·04556	80	·13553	80	·27334	80	·45899
400	0·00383	1400	0·04689	2400	0·13781	3400	0·27658	4400	0·46320
20	·00422	20	·04824	20	·14012	20	·27985	20	·46742
40	·00462	40	·04961	40	·14244	40	·28313	40	·47166
60	·00506	60	·05100	60	·14480	60	·28643	60	·47591
80	·00551	80	·05241	80	·14715	80	·28975	80	·48020
500	0·00598	1500	0·05383	2500	0·14954	3500	0·29309	4500	0·48449
20	·00647	20	·05528	20	·15194	20	·29644	20	·48881
40	·00697	40	·05674	40	·15436	40	·29982	40	·49316
60	·00750	60	05822	60	·15680	60	·30323	60	·49749
80	·00805	80	·05972	80	·15926	80	·30664	80	·50189
600	0·00861	1600	0·06125	2600	0·16173	3600	0·31008	4600	0·50627
20	·00920	20	·06279	20	·16423	20	·31353	20	·51067
40	·00980	40	·06435	40	·16675	40	·31700	40	·51511
60	·01042	60	·06593	60	·16929	60	·32050	60	·51957
80	·01106	80	·06753	80	·17184	80	·32401	80	·52404
700	0·01172	1700	0·06914	2700	0·17441	3700	0·32754	4700	0·52852
20	·01240	20	·07078	20	·17701	20	·33110	20	·53302
40	·01310	40	·07244	40	·17962	40	·33466	40	·53755
60	·01382	60	·07411	60	·18225	60	·33825	60	·54211
80	·01456	80	·07581	80	·18490	80	·34186	80	·54667
800	0·01531	1800	0·07752	2800	0·18758	3800	0·34548	4800	0·55124
20	·01609	20	·07925	20	·19026	20	·34913	20	·55586
40	·01688	40	·08100	40	·19298	40	·35280	40	·56048
60	·01769	60	·08277	60	·19571	60	·35650	60	·56512
80	·01853	80	·08456	80	·19844	80	·36018	80	·56978
900	0·01938	1900	0·08637	2900	0·20121	3900	0·36390	4900	0 57447
20	·02025	20	·08820	20	·20400	20	·36766	20	·57917

Smaller scales are usually employed in extensive operations: six inches to 1 mile is a large scale for the survey of a county, and is the one employed in drawing the plans of the Ordnance Survey of Ireland. The English survey is published on a scale of one inch to a mile.

The plans and sections for projected railways, &c. deposited with the Houses of Parliament, to obtain the sanction of the Legislature, are required to be drawn on scales, not less than 4 inches to the mile for the plan, and one hundred feet to the inch for the section.

ceive the lines forming the observed angles, and it may be applied to the paper as above described, the centre of the graduated arc showing the situation of the boat on the chart.

The position of the boat may also be determined geometrically, as follows; (but this would be too tedious a process where a great number of stations are to be determined.) Let A B C be three fixed objects on shore, and from the boat at D, suppose the angles C D B and B D A were found = 40° and 60°. Subtract double the angle C D B from 180°, and take half the remainder = 50°, and lay off this angle from C and B, the two lines will meet in E, which will be the centre of a circle passing through B, C, and the place of the boat, which will be somewhere on this circle. To find the exact point, take double the angle, B D A, from 180°, and lay off half the remainder = 30° from B and A; these lines will meet in a point, F, which will also be the centre of a circle passing through A, B, and the place of the boat; consequently, where these two circles intersect each other, viz. at D, will be the situation of the boat on the plan, with regard to the shore, as required.



In conclusion, it may be useful to add a few remarks on the scales used in plotting the work of a survey.

One chain to an inch (80 inches to 1 mile) is perhaps the largest scale used in plans of land and road surveys, and is adopted only when great clearness is required, and when the work is of limited extent. It is a very useful scale for plans of building or pleasure grounds.

Two chains to an inch (40 inches to 1 mile) is a very clear scale for land surveys, the extent of which is not very great. It may likewise be used with advantage for gardens and building grounds.

Three chains to an inch (26$\frac{2}{3}$ inches to 1 mile) has hitherto not been in very general use, but has lately been adopted by the Tithe Commissioners for the scale of their plans, considering it as "the smallest scale that can with safety be used, in all cases for plans from which the contents are to be computed."

This instrument consists of three rulers, A B C, (fig. 1,) co nected together by a common centre upon which they turn, an can be opened to form two angles of any inclination. The rul B is connected with the circular arc, *b*, the ruler, C, with the ar *c*, and the middle ruler, A, with the two verniers, *a a*, adapted the two arcs. The middle ruler is double, and has a fine wire thread stretched along its opening; the other rulers have lik wise a fine wire stretched from end to end, and so adjusted the little projecting pieces which carry them, that all the thr wires tend to the centre of the instrument, where they wou meet if produced. The graduated circular arcs, *b* and *c*, are f setting the rulers, or rather the fine wires, at whatever angl they may be required to form at the centre of the instrumen Through the centre is an opening sufficiently large to admit steel pricker, (fig. 2) to be gently pressed into the paper, whe the instrument is adjusted in its position: the puncture th made will represent the station required.

That the application of the instrument may the more readi be understood, we have represented it in the act of being use Suppose the points marked D E F to be three conspicuous o jects on the coast, whose relative situations are known and la down upon the map; and that, on exploring the offing in a boa a remarkable sounding occurred, which it was necessary shou be marked in the chart, the situation of the boat, at the time t sounding was taken, with regard to the shore, must therefore determined: with a sextant measure the angle, subtended the objects F and E, likewise the angle subtended by D and which suppose to be 35° 10′, and 20° 50′, then to lay down the chart the position of the boat, open the rulers of the statio pointer, and by the circular arcs, set them to the observed angle lay the instrument on the paper, and move it till the three wir pass through the three fixed objects; the centre of the instr ment will then occupy the relative situation of the boat, and the steel pricker, the place may be marked on the paper. Whe several soundings have been taken, and angles observed at t time to any three fixed objects, the station-pointer affords gre facility in laying them down: thus the position of shoals, sunk rocks, &c., may be correctly determined.*

In the absence of the station-pointer, a substitute may be o tained, by drawing on a piece of tracing-paper three lines for ing the observed angles, and moving them about till they pa through the three fixed objects, and the angular point of the angles will then occupy the position of the boat. A very go station-pointer may be made by graduating an arc of a circle a piece of plate glass, one side of which must be ground to compass, or the angles subtended by these points and the other boat are measured by a sextant. Having now on paper drawn the base to any scale, straight lines radiating from each end at the observed angles, will, by their intersections, give the positions of the several points from which the coast may be sketched. But a chart is more accurately constructed, by combining a survey made on land, with observations taken on the water. A smooth level piece of ground is chosen, on which a base of considerable length is measured, and station staves are affixed at its extremities. If no such place can be found, the mutual distance and position of two points conveniently situated for planting the staves, though divided by a broken surface, are determined from one or more triangles, connected with a shorter and temporary base measured near the beach. A boat then explores the offing, and at every rock, shallow, or remarkable sounding, the bearings of the station staves are noticed. These observations furnish so many triangles, from which the situation of the several points are easily ascertained. When a correct map of the coast can be procured, (or previously constructed) the labour of executing a maritime survey is materially shortened. From each important point on the water, the bearings of two known objects on the land are taken, or the intermediate angles subtended by three such objects are observed." The situation of the observer at the time such angles are taken, may then be laid down by means of an instrument called a station-pointer, which is represented in the annexed figure, and which we shall now describe.

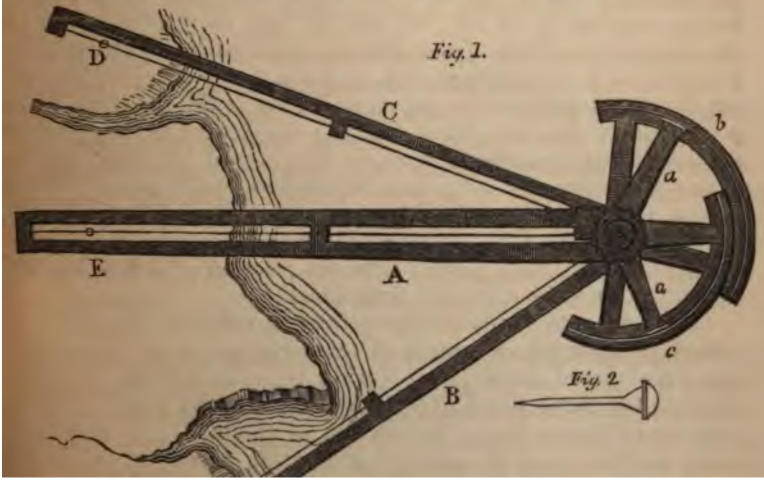


Fig. 1.

Fig. 2

number of fences, give so many fixed points to take bearings from, as frequently to reduce his labour materially, both in the field, and afterwards in plotting the work.

Having proceeded onward with the measurement of his first main line, as far as may be convenient for his purpose, and also completed the measurements branching therefrom, the surveyor must again set up his compass at the point where he wishes to change the direction of his course, or commence a *second* main line, when having taken the bearing of some natural conspicuous object in the required direction, he must proceed to measure such second line, and all its subsidiary dimensions, in the same manner as before, completing as much as possible all the minor measurements depending on each main line before he commences a new one.

Such is the general method of procedure; but as every thing depends upon the experience and tact of the surveyor, it is impossible to give more than a *general description: particular* rules for surveying are useless, as new cases, and sometimes difficult ones, are hourly occurring, which the experience of the surveyor alone will enable him to overcome, and suggest at the time a method which no book, in all probability, could inform him of.

The protraction of a railway survey is the most easily performed by having a protractor laid down upon the plot itself, from which the angles can be transferred by a parallel ruler to any part of the work as described at page 118; but instead of constructing a protractor in the manner there directed, it may be done by laying on the paper a metallic circular protractor, placing the zero divisions, (180° and 360°) in the exact position it may be necessary to have the meridian represented, then prick off, and mark *all* the degrees, and if sufficiently large, the *half degrees* also; thus a protractor may be drawn on the paper ready for use in a very few minutes; the plotting is then performed in a manner so precisely similar to that described for the traverse of a road survey, at page 118, that to enter upon the subject here would be merely a recapitulation of what is there stated, to which we accordingly refer.

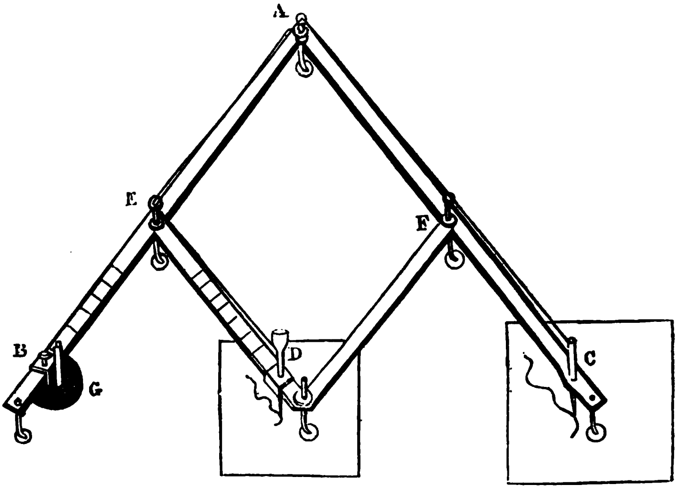
"Maritime surveying is of a mixed kind: it not only determines the positions of the remarkable headlands and other conspicuous objects that present themselves along the vicinity of a coast, but likewise ascertains the situations of the various inlets, rocks, shallows, and soundings, which occur in approaching the

When it is required to make an enlarged copy of a plan, the setting of the instrument is precisely the same as above stated, only the tracing point and pencil must change places, the original being placed under D, and the copy under C. But when a copy is to be made of the same size as the original, the fulcrum must be placed in the middle at D, and the pencil at B, under which will be the copy, whilst the original must be placed under the tracing point at C.

When a survey is to be made for the purposes of a line of railway or turnpike-road, it is necessary to delineate not only the fields through which it is contemplated the line would pass, but also one or more fields on each side, to the extent of full one hundred yards, for the purpose of admitting hereafter, if necessary, an alteration to that extent at any point on the line. The instrument usually employed on such surveys is, the prismatic compass, described at page 3 (or else a circumferentor,) together with a land-chain.

To execute a survey of this kind, supposing the line to have been previously chosen, the surveyor must set up his compass at one extremity of the work, and take the bearing of some distant object situated in the direction of the intended line of railway or road; having done which, and entered it in his field-book, he must commence chaining in that direction, taking offsets to the fences of the fields, and every remarkable object within a short distance to the right and left of his line; he must also note the point at which his chain crosses the various fences, and at the same time and place set up his compass, to observe the *bearing* of such fences, or, in other words, the angle their direction makes with the meridian: this angle is at once given by the compass, and furnishes data for laying down their *position* with regard to the main line which crosses them, but does not determine their respective lengths; the surveyor must therefore measure along the side of each fence, both to the right and left of the point at which he crosses it, till he comes to their extremity, or the points where such fence meets the other, or side fences of the field; these now become known or fixed points, from whence the *bearing* of every fence which diverges from this may be taken, giving the means of laying down their several directions on the general plan.

ment turns. Several ivory castors support the surface of the machine parallel to the paper, as well as facilitate its motions.



The arms, ED, and EB, are graduated and marked with the ratios, $\frac{1}{2}$, $\frac{1}{3}$, &c. so that when a copy of a plan is required to be made in any of these proportions, it is only requisite to fix, at the required ratio, the slides carrying the fulcrum, G, and the tube at D, with a pencil or pen, and the instrument will be ready for operation. Thus, suppose it were required to make a copy of a plan exactly one half the size of the original, our engraving represents the pentagraph so employed; the slide carrying the pencil at D, and that working on the fulcrum, G, are each fixed by their respective clamp-screws at the divisions marked $\frac{1}{2}$, the original plan is placed under the tracing point, C, and exactly parallel to it is placed a sheet of paper under the pencil, D; the pentagraph being first spread out so as to give room for the tracing point to be passed over every line on the plan, whilst the pencil at D is making corresponding marks on the copy, which it is evident will be equal to one half the size of the original. A fine string is attached to the pencil-holder, and passed round by E A, &c. to the tracing point, the pulling at which raises the pencil a small quantity above the paper, to prevent false or improper marks upon the copy. It should also be remarked, that the cup represented on the top of the pencil-holder is intended to receive a weight, to keep the pencil down upon the paper, or when a stronger mark is required.

Tracing paper is sometimes thus used for making a copy of the whole plan, but as this process occupies so much time, it is frequently applied in the following manner: A sheet of tracing, or bank-post paper, having one side covered with powdered black-lead, is laid between the original and the copy, the former being uppermost; a tracing point is then carefully passed over all the lines on the plan with a slight pressure, depending upon the thickness of the paper, the sheet beneath will receive corresponding marks forming an exact copy, which may be inked in at leisure.

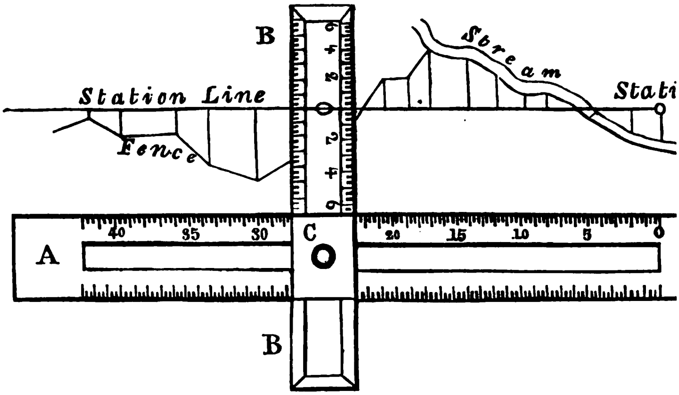
Another method is by means of a large piece of plate glass, called a copying glass, upon which the plan is placed with a fair sheet of paper uppermost, the glass being then fixed in such a position as to have a strong light fall upon it behind, the whole plan becomes visible through the sheet of paper, upon which a fair copy can be made without the danger of soiling or injuring the original by pricking through, &c.

When a plan is to be copied upon a reduced or enlarged scale, other means must be resorted to, which are also applicable to copying upon the same scale. One of them is by the use of proportional and triangular compasses, which it is only necessary to mention; another is by dividing the surface of the original into a great number of small squares, and drawing a similar number upon the copy, which must be formed larger or smaller than those on the original, in the exact proportion of the required difference of the scales; the squares in the latter may then be filled up with the same detail of the plan as is contained in the corresponding squares on the former. When, from the great value of the original, it becomes improper to draw lines upon or otherwise deface it, recourse has been had to a frame of wood or metal, having fine threads stretched across it each way, forming a series of squares: this being laid upon the plan, will, if accurately done, answer the same purpose.

The last method we shall speak of is by means of a well-known instrument called a pentagraph.

The subjoined engraving represents the pentagraph, which consists of four flat rulers, made either of wood or brass; the two outside ones are generally from 15 to 24 inches long, and the others about half that length; the longer ones, A B, and A C, are united together at A, by a pivot about which they turn, and the two smaller rulers are similarly attached to each other at D, and to the longer rulers at E and F. A sliding box is placed on each of the arms, A B and E D, which may be fixed by a clamp

B, either to the right or left of the station line, to which it will right angles as taken in the field; the instrument thus gives dimensions at the same time. It is perhaps needless to add, the extremities of the offsets being connected, will repr the curved line, &c., to which they were measured; weights be placed at the two ends of the scale, A A, to keep it ste in its position. In our figure, the instrument is represent in the act of plotting offsets upon a station line.



It very frequently happens that a surveyor requires cop be made of his plans, and these occasionally on an enlarg diminished scale. There are various methods of accompli this purpose, some of which we shall here enumerate.

When a copy is to be made of the same size as the ori it is a common practice to lay the plan upon the sheet of intended for the copy, and press them close together by of weights; then with a fine needle prick through all the cc and leading points on the plan, making corresponding pun in the paper beneath, which may then be connected by li complete the copy. But when the lines on the original ar crooked, this method cannot be successfully applied witho aid of a pair of compasses and tracing paper; when, h pricked off the principal points, the remainder may be fou the compasses, and the curved lines transferred by drawing on tracing paper the back of which being rubbed over and the centre of the protractor, must (for the instrument to be correct) be in the same straight line. The points are prevented from scratching the paper as the arms are moved round, by steel springs, which lift the branches a small quantity, so that, after setting the centre of the protractor over the angular point, and the vernier in its required position, a slight downward pressure must be given to the branches, and each of the points will make a fine puncture in the paper; a line drawn through one of these punctures and the angular point will be the line required to form the angle.

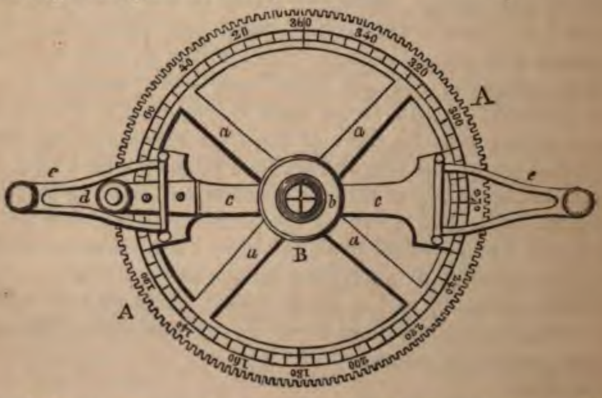
Any inaccuracy in placing the centre of the protractor over the angular point may easily be discovered, for, if incorrectly done, a straight line drawn through the two punctures in the paper will not pass through the angular point, which it will do, if all be correct.

The face of the glass centre-piece on which the lines are drawn is placed as nearly even with the under surface of the instrument as possible, that no parallax may be occasioned by a space between the lines and the surface of the paper.

By help of the vernier the protractor is graduated to single minutes, which, taking into consideration the numerous sources of inaccuracy in this kind of proceeding, is the smallest angular quantity that we can *pretend* to lay down with certainty. Greater accuracy may perhaps be obtained by the help of a table of natural sines and a well-graduated beam-compass, as explained at page 114.

For plotting offsets, measured to the right and left of the station lines, ivory scales with fiducial edges are usually employed. The figure in the following page represents an ingenious contrivance for an offset scale, extensively employed on the Ordnance Survey of Ireland.

cular metallic protractor; as the kind of protractor we have just been describing would not answer the purpose, its chief use being, as has been already described, to plot a traverse upon a moderately small scale. There are several constructions of the protractor adapted to the purpose now under consideration, but the most approved is represented in the subjoined figure. It consists of an entire circle, A A, connected with its centre by four radial bars, *a a*, &c. The centre of the metal is removed, and a circular disk of glass fixed in its place, on which are drawn two lines crossing each other at right angles, and dividing the small circle into four quadrants, the intersection of the lines denoting the centre of the protractor. When the instrument is used for laying down an angle, the protractor must be so placed on the paper, that its centre exactly coincides with, or covers the angular point, which may easily be done, as the paper can be seen through the glass centre-piece.



Round the centre, and concentric with the circle, is fitted a collar, *b*, carrying two arms, *c c*, one of which has a vernier at its extremity, adapted to the divided circle, and the other a milled head, *d*, which turns a pinion, working in a toothed rack round the exterior circle of the instrument; sometimes a third arm is applied at right angles to the other two, to which the pinion is attached, and a vernier can then (if required) be applied to each of the other two, and it also prevents the observer disturbing that part of the instrument with his hand when moving the pinion. The rack and pinion give motion to the arms, which can be thus turned quite round the circle for setting the vernier to any angle that may be required. Upon a joint near the extremity of the two arms (which form a diameter to the circle) turns a branch, *e e*, which for packing may be folded over the

the former shall coincide with the meridian-line drawn upon the latter, and to prevent it shifting, lay weights on its corners. Place the edge of a large parallel ruler on the divisions which were read off for the forward angle to *b*, and slide the ruler parallel to itself till its edge passes through the station, *a*, and draw a line from *a* in the direction, *a b*, then with a pair of compasses, and from the scale of the plot, lay off the distance, *a b*, which will determine the point *b*. Next place the edge of the ruler on the angles taken at *b*, to the stations *r* and *c* respectively, and slide it parallel to itself, till its edge passes through *b*, then draw the lines, *b r*, and *b c*, and lay off those distances from the scale of the plot, and the stations *r* and *c* will be fixed. Next set the ruler to the forward angle taken at *c* to the station, *d*, and move it till its edge passes through *c*, and draw the line, *c d;* lay off the distance, *c d*, and the station *d* will be determined. In like manner proceed with the remaining stations of the survey, until you come to the point, *m*, when, if the lines have been correctly measured and protracted, the forward angle will pass through the station, *b*, and the distance exactly correspond. If the lines have been measured on very uneven ground, each of them must be reduced to the horizontal measure, which may be done at the time of measuring them, by the vertical arc of the theodolite, (see pages 2 and 17.)

The bearings taken at different stations to various conspicuous objects, are to be laid down as the plotting of the forward angles proceed, for when several bearings have been taken to the same object, the crossing of such lines in the same point is a proof of the relative accuracy of the work, and if these objects have been independently fixed and laid down by triangulation, the bearings will then prove the accuracy of the work with respect to these fixed points.

We have remarked that the plotting must be performed within the circle forming the protractor, which direction is to be understood as applicable only when the protractor is not on the same paper with the plot, for when it is on the same paper, the angles may be transferred by the parallel ruler to any part of the sheet; but care must be taken in numbering the divisions of the protractor, so that the working meridian may be in the best direction for getting into the sheet the greatest portion of the survey. If the protractor is on a separate sheet, and the work has proceeded to its edge, it must be shifted on the paper in the direction of the survey, but must be moved exactly parallel to itself, which may easily be done by drawing more meridian lines parallel to the first meridian, on which to place the protractor, as in the first instance.

Next set the compasses to the natural sine of 15°, which t radius *five*, will be equal to the chord of 30°, and this distanc will bisect each 60° and divide the circle into arcs of 30° eack A proof may be obtained of the accuracy of the work as i proceeds, by setting the succeeding chords off each way, froı those points which they are intended to bisect; for if any inac curacy exists, the bisection will not be perfect, and if the errc proves inconsiderable the middle point may be assumed a correct.

Each sixty degrees may next be trisected, by setting off th natural sine of 10° (equal the chord of 20° to our radius) whic will divide the circle to every ten degrees.

Next the natural sine of 7° 30′ (equal the chord of 15 stepped from the points already determined, will divide the circl to every fifth degree.

The natural sine of 3° (equal the chord of 6°) being laid of divides 30° into five parts, and set off from the other division divides the circle to single degrees.

Fifteen degrees bisected, or the natural sine, 3° 45′ (equa the chord of 7° 30′) set off from the other divisions, divides th circle into half degrees.

The natural sine of 3° 20′ (equal the chord of 6° 40′) divide 20° into three parts, and set off from the rest of the division divides the whole circle to every ten minutes, which is as minut a subdivision as such a circle will possibly admit of; smalle quantities must therefore be estimated by the eye. The div sions should be numbered from 0, 10°, 20°, &c. quite round th circle to 360°, the same as the theodolite, which the protracto represents.

It may be considered troublesome to lay down a protractor this kind upon every sheet of paper to be plotted on, but havin done one, several copies may be obtained from it, by prickin through the divisional points upon paper placed under it for th purpose. Or, if made upon a sheet of card-board, the pape within the graduated circle must be cut out, as the work is plotted within the circle forming the protractor.

Suppose, with a protractor of the latter kind, we proceed t lay down the work of our survey. First draw a line througl the assumed starting point, *a*, across the paper, to represent th magnetic meridian; or, if the points, A B, &c. have been fixe by previous triangulation, they should be laid down and a line drawn through *a*, and any one of them (which has been observed from *a*) may be assumed as a working meridian; then across the protractor draw a line, through the same divisions that were noted on the theodolite for the reading of the meridian which not correctly determined, these bearings will not all intersect in the same point on the plan. The last operation at each station is to measure the forward angle. In this manner proceed to the stations *d*, *e*, *f*, *g*, &c., and having arrived at *g*, measure an angle to the pole, A, as to a forward station, and placing the theodolite upon that spot, direct the telescope to *g*, as a back station, in the usual way; this done, release the upper plate, and direct the telescope to the *first* station *a*, from which A had been observed, and if all the intervening angles have been correctly taken, the reading of the two verniers will be precisely the same as when directed to A from the station *a*: this is called closing the work, and is a test of its accuracy so far as the angles are concerned, independent of the compass-needle. If the relative situation of the conspicuous points, A B, &c., were previously fixed by triangulation, there would be no necessity to have recourse to the magnetic meridian at all, as a line connecting the starting point *a* with any visible *fixed* object, may be assumed as a working meridian, and if it be thought necessary, the reading of the compass-needle may be noted at *a*, when such fixed object is bisected, and upon the theodolite being set to the reading of this assumed meridian, at any subsequent station, the compass-needle will also point to the same reading as it did at first, if the work is all correct, and no local attraction influences the compass.

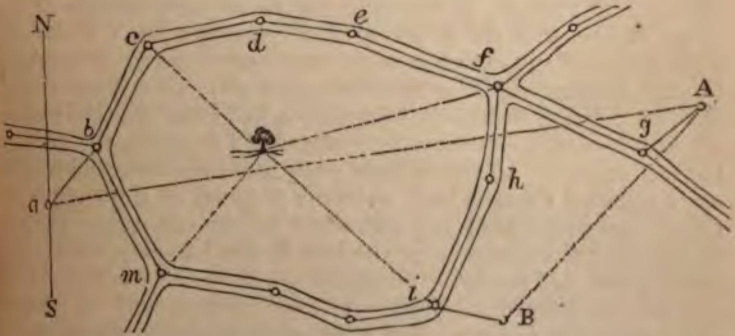
While the instrument is at A, take angles to all the conspicuous objects, particularly to such as you may hereafter be able to close upon, which will (as in the above instance) verify the accuracy of the intervening observations; having done this, return to *g* and *f*, &c. and proceed with the survey in the same manner as before, setting the instrument up at each bend in the road, and taking offsets to the right and left of the station lines; arriving at *i*, survey up to, and close upon B; then return to *i*, and proceed from station to station till you arrive at *m*, where, if the whole work is accurate, the forward angle taken to *b* will be the same as was formerly taken from *b* to *m*, which will finish the operation.

The next step is to lay down the lines and angles thus surveyed; and first, the protractor must be constructed. The great difficulty of dividing a circle accurately is well known, but if the arcs are laid off by means of their chords, the division may be performed with sufficient exactness for the purpose in hand. The length of the chords should be taken from an accurately divided beam-compass, which, to insure success, should be set with the utmost possible exactness.

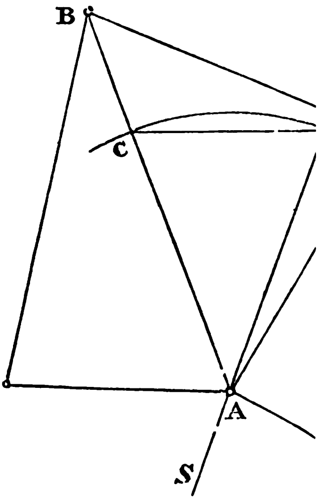
the two readings in the field-book; likewise in the same mani take bearings, or angles, to all such remarkable objects as likely to be seen from other stations, as the tree situated o hill; and lastly, take the angle to your forward station, *b*, wh an assistant must hold a staff for the purpose, on a picket dri into the ground,* in such a situation as will enable you to t the longest possible sight down each of the roads that m there. In going through the above process, at this and ev subsequent station, great caution must be used to prevent lower horizontal plate from having the least motion after be clamped in its position by the screw H.

Next measure the distance from *a* to *b*, and set up the inst ment at *b*, release the clamp-screw H *only*, not suffering upper plate to be in the least disturbed from the reading it when directed at *a* to the forward station *b*, with the instrum reading this forward angle; turn it bodily round, till the te scope is directed to the station *a* (which is now the back stati where an assistant must hold a staff; tighten the clamp-screw and by the slow-motion screw, I, (page 15) bisect the staff as ne the ground as possible, and having examined the reading, to s that no disturbance has taken place, release the upper plate, a setting it to zero, see if the magnetic needle coincides, as in t first instance, with the N S line of the compass-box; if it doe all is right; if not, an error must have been committed in takin the last forward angle, or else the upper plate must have move from its position before the back station had been bisected: whe this is the case it is necessary to return and examine the work a the last station. If this is done every time the instrument is se up, a constant check is kept upon the progress of the work; an this indeed is the most important use of the compass. Havin thus proved the accuracy of the last forward angle, release th upper plate, and measure the angles to the stations *m* and *r*, and as before, to whatever objects you may consider will be conspicuous from other places; and lastly, observe the forward angle to the station *c*, where the theodolite must next be set up, and measure the distance *b c*.

At *c*, and at every succeeding station, a similar operation must be performed, bisecting the back station with the instrument reading the last forward angle; then take bearings to every conspicuous object, as the tree on the hill, the station, A, &c., which will fix their relative situations on the plan, and they afterward serve as fixed points to prove the accuracy of the position o such other stations as may have bearings taken from *them* to th same obiect: for, if the relative situations of such stations ar remedy in some measure this inconvenience, it has been recommended that the apartments appropriated to the purposes of drawing should be constantly kept in as nearly the same temperature as possible, and also that the intended scale of the plan should be first accurately laid down upon the paper itself; and from this scale all dimensions for the work should invariably be taken, as the scale would always be in the same state of expansion as the plot, though it may no longer retain its original dimensions. The protractor may also be laid down upon the paper; and when a great many angles are to be plotted, as in a road or town survey, made with a theodolite and chain, especially if done by traversing, or what is frequently called surveying by the back angle, this kind of protractor will enable the draftsman to plot the work with great rapidity, and with less chance of error, when the scale is small, than by the method of laying off angles by placing the centre of a metallic protractor at every angular point, and pricking off the angle from its circular edge. The application of the theodolite to surveying by a traverse, as well as the method of protraction, we shall endeavour to explain by means of an example.



Let the above plan represent a survey of roads to be performed with a theodolite and chain. Commencing on a conspicuous spot, *a*, near the place at which two roads meet, the theodolite must be set up and levelled, the upper and lower horizontal plates clamped at zero, and the whole instrument turned about until the magnetic needle steadily points to the N S line of the compass-box, and then fixed in that position by tightening the clamp-screw, H, (see page 15.) Now release the upper plate, and direct the telescope to any distant conspicuous object within or near the limits of the survey, such as a pole purposely erected in an accessible situation that it may be measured to, and the tain a corresponding degree of exactness, recourse must b(some other method, and the following is the best that w seen practised.



Let A and B represent two stations of a trigonometrical survey; and let it be required to lay off the direction of the true meridian, N S, with regard to the line A B, the azimuth of which, *west* of *north*, being 40° 30′ 30″. Take from an accurately divided diagonal scale, exactly five inches as a radius, and from A, as a centre, describe an arc C D; now the chord of an arc being equal to twice the sine of half that arc, it follows that the chord C D is equal to twice the natural sine of half the angle C A D or B A D, viz., 20° 15′ 15″; but the radius tables of natural sines being = 1 or 10, and taking but t of 10, or 5 inches for our radius, we must take from th the natural sine of *half* the angle B A D, which will, to ra be equal to C D, the chord of the whole angle; and having that distance from the same scale of inches as the radius, pl foot in the point C, and with the other mark the point D arc C D, then through D and A draw the line N S, whi represent the meridian. But instead of employing a pair o passes and a scale for this purpose, it is better to use a compass, graduated to inches, and having a vernier for subdivision, as a measure of length can be taken by its with greater exactness, than by a pair of compasses scale.

This method of laying off angles may be convenientl ployed in dividing a circle to be used as a protractor, wh work is to be laid down to a scale not exceeding six in a mile. The protractor may be made either on the same of paper intended to receive the drawing, or on a separat of card-board, when it may be preserved and used on afte

APPENDIX.

ON PROTRACTING AND PLOTTING, &c., AND THE INSTRUMENTS EMPLOYED.

IN the execution of extensive surveys upon scientific principles the accurate measurement of angles is of the utmost importance, requiring the employment of instruments of a superior construction, as well as considerable care and skill in their management. And one great object of such surveys being the formation of correct maps and charts, it is no less essential, that the angles, when accurately measured, should be accurately laid down. We therefore purpose to describe briefly, in this Appendix, the most approved methods of laying down angles, &c., as supplementary to our account of surveying instruments.

Extensive surveys are best performed, by extending a series of triangles over the country to be delineated; and from the length of a side of one triangle measured or otherwise determined, as a base, and the angles found by means of appropriate instruments, the lengths of the various lines forming the sides of the several triangles throughout the series are computed. The accuracy of the distances thus obtained, will depend on the correct measurement of the angles; and the distance assumed as a base, provided due attention be paid in the first instance to the judicious dispositions of the triangles, which ought to be as nearly equilateral as circumstances will admit. The accurate protracting of the triangles thus determined, is of the next importance. They can be more correctly laid down by means of their sides than by their angles; and one side only, for measures of length, can be taken from a scale and transferred to paper, with more exactness than an angle can be pricked off from a protractor. But it being in most cases requisite, in plotting a survey, to show the direction of the meridian with regard to the triangulation, it becomes necessary to lay down, from one of the principal stations, the azimuthal angle subtended by some other (remote) station and the meridian: now this angle cannot be laid off from a protractor, even of the most approved construction, and longitude; divide the distances A D and B D by those numbers, and the quotients will be the difference of longitude an latitude (in arc) required. Thus:

$$\frac{\text{A D} = 5064\cdot 8}{\text{Table} = 63\cdot 31} = 80{,}44'' = 1'\ 20{,}00'' = \text{diff. of long. in spac}$$
$$= 5^{s}{,}33 \text{ in time.}$$

$$\frac{\text{B D} = 3292\cdot 2}{\text{Table} = 102\cdot 02} = 32{,}27'' \text{ difference of latitude.}$$

		M.	S.	
Longitude of A	=	21	10,40	West.
Difference			5,33	East.
Longitude of B	=	21	5,07	West.

		°	′	″	
Latitude of A	=	51	27	44,00	North.
Difference......			0	32,27	South.
Latitude of B	=	51	27	11,73	North.

Lastly, we shall give the method of finding the longitude by observations of the eclipses of Jupiter's satellites.

The Nautical Almanac contains the Greenwich mean time when the phenomena happen, consequently the estimated longitude of the place being applied to the time therein given, will be the time at which an eclipse may be expected to happen at the station of the observer, who, being at his telescope a few minutes before, should steadily watch the spot near the body of the planet where the phenomenon is expected, till he discovers the first glimpse or point of light appear, if it be an emersion from the shadow, or of the final disappearance, if an immersion; noting, by a previously regulated time-keeper, the exact mean time (at his own station) when this happens. The difference between this time and the Greenwich time given in the Nautical Almanac, will b the longitude in time; east, if the Greenwich time is less tha that observed, otherwise west. Before the opposition of th planet to the sun, the eclipses always happen on the west sid of the planet, and afterwards on the east. But when using a inverting telescope, the appearance will be reversed. The situ tion of the satellite with respect to the planet where the eclip takes place, is given in the Nautical Almanac.

° ′ ″
39 26 45·5 ½ star's azimuth, tan. = 9·9152706
2

78 53 31·0 = azimuth of star
42 3 4·0 object nearer meridian

36 50 27·0 = azimuth of object east of south.

The verification of the meridional position of an instrument by observing the passage of a circumpolar star at both its upper and lower culminations, as well as the method by high and low stars, has been fully explained, when speaking of the transit; and as the altitude and azimuth circle, when firmly clamped in the plane of the meridian, becomes a complete transit instrument, and may be employed precisely in the same manner and for the same purposes, we refer for this use of it to the account which we have given of that instrument.

In addition to the method of determining differences of longitude by the observed transits of the moon and moon-culminating stars, (page 88,) we subjoin the following as applicable to the use of the instrument which we are now describing. The latitudes and longitudes of a great number of the most conspicuous places in this country, as church steeples, &c., having been determined, and published in the account of the Ordnance Survey, they afford a ready means of finding both the latitude and longitude of places adjacent to them, by means of trigonometrical measurement. The process may be understood from the following example.

Let A represent a place, the longitude and latitude of which are known; B the station, the situation of which we wish to determine; C any point to form the triangle; N S the direction of the meridian.

Practical Rule. Add together the polar distance, the co-latitude, and the zenith distance, and call their sum S. To the log. sine of half S *minus* the zenith distance, add the log. sine of half S *minus* the co-latitude, and increasing the index by 20, call the sum of the two logs. A.

To the log. sine of half S add the log. sine of half S *minus* the polar distance, and call the sum of the two logs. B.

From A subtract B, and divide the remainder by 2; the quotient will be the log. tangent of half the object's azimuth, which doubled will be the whole azimuth, or horizontal angular distance from the south meridian.

EXAMPLE.

On February 20, 1834, in latitude 51° 28′ 39″. The zenith distance of *a* Geminorum (east of the meridian) corrected for refraction = 56° 20′ 10″, the azimuth circle reading 125° 18′ 24″: after which the clamps of the instrument were released, and a fixed terrestrial object bisected, also to the *east*, but nearer the meridian than the star, the azimuth circle now read 83° 15′ 20″, consequently the horizontal angle between the star and the object = 42° 3′ 4″ required the azimuth of the object from the meridian.

$$\begin{array}{lrrrl}
 & {}^{\circ} & {}' & {}'' & \\
\pi\,(\text{from the N.A.}) = & 57 & 45 & 16 & \\
\lambda\;.\;.\;.\;.\;.\;= & 38 & 31 & 21 & \\
z\;.\;.\;.\;.\;.\;= & 56 & 20 & 10 & \\
\hline
2)\; & 152 & 36 & 47 & \\
\hline
\frac{s}{2} = & 76 & 18 & 23 & \\
\hline
\frac{s}{2} - z\;.\;.\;.\;= & 19 & 58 & 13 & \text{sine} = 9{\cdot}5334322 \\
\frac{s}{2} - \lambda\;.\;.\;.\;= & 37 & 47 & 2 & \text{sine} = 9{\cdot}7872371 \\
 & & & & A = 9{\cdot}3206693 \\
\frac{s}{2}\;.\;.\;.\;.\;= & 76 & 18 & 23 & \text{sine} = 9{\cdot}9874766 \\
\frac{s}{2} - \pi\;.\;.\;.\;= & 18 & 33 & 7 & \text{sine} = 9{\cdot}5026514
\end{array}$$

carefully elevate the telescope to the star itself, which will also be bisected if the estimation of half the amount of deviation has been correctly made, and if not, it will be a nearer approximation, which must be perfected by a similar process, that is, by removing half the error with the foot-screws, and the other half by the horizontal circle.

Having now set the instrument, so that, upon elevating and depressing the telescope, both the direct and reflected images of the star appear bisected, a satisfactory observation will have been made. This being done at both the eastern and western elongations, and the readings of the azimuth circle noted, the middle point between the two readings will lie in the plane of the true meridian. Or, as before observed, one observation may be made available for the same purpose, by likewise observing a fixed object, as a lamp or church tower, and computing, by the foregoing rule, the azimuth of the star at that time, for the horizontal angle between the star and the fixed object, plus or minus the computed azimuth of the star (plus when the object is on the same side of the meridian, and further from it than the star; and minus, when it is nearer the meridian than the star, or when they are on opposite sides of the meridian) will give the azimuth of the fixed object from the north, from which the direction of the meridian may be found at any time.

It is only stars whose polar distance is less than the co-latitude of the place of observation, that can be used in the two latter methods of determining the direction of the meridian.

The last method which we shall advert to, and which is mostly applied to objects south of the zenith, consists in computing the azimuth of a celestial object, from an observation of its altitude, the latitude being known; at the same time observing the horizontal angle contained between it and any fixed object; for the difference or sum of the azimuth of the celestial body, and this observed horizontal angle, will be the angular distance of the fixed object from the meridian: the sum when the fixed object is on the same side of, and further from, the meridian than the celestial object, otherwise, the difference.

Formula for computing the azimuth of a celestial object from its observed altitude, &c.

$$\text{Tang. } \tfrac{1}{2} \text{ azimuth} = \sqrt{\frac{\sin.\frac{s}{2} - z.\ \sin.\frac{s}{2} - \lambda}{\sin.\frac{s}{2}.\ \sin.\frac{s}{2} - \pi}}$$

muth (east or west) of a star, when at its greatest elongation, ε well as the time of its attaining such position, must be compute (which may be done by the annexed rules), when the observ must first bisect the star, and follow it in its slow motion, unt he is satisfied that it is stationary; or, what is perhaps bette if he is certain of his time, bisect it at the exact moment. Tl azimuth circle must now be read off, and the position of son fixed object, with respect to the azimuth of the star, should l determined; a lamp may at the time be placed at some distan for reference, and its azimuth being thus obtained, other objec may be referred to it at leisure.

To compute the azimuth of a circumpolar star, when at i greatest elongation.

Rule. From the log. sine of the polar distance, subtract th log. co-sine of the latitude: the remainder will be the lo sine of the azimuth required.

To compute the time (before or after its meridional passage) (a circumpolar star attaining its greatest elongation, eith east or west.

Rule. Add together the log. tangent of the polar distanc and the log. tangent of the latitude: their sum, rejecting te from the index, will be the log. co-sine of the hour-angle (i space); which, divided by fifteen, will be the sidereal time a sta attains its greatest elongation before or after it passes the mer dian at its upper culmination; therefore, having the time of th meridional passage (computed, as explained at page 82) the tim of its greatest elongation will be known.

The star *a* Ursæ Minoris, commonly known as the pole-star, is well situated for determining the direction of the meridian by the above method: its apparent motion when near its greatest elongation is so small, that it appears stationary at that point for a considerable time, affording us an opportunity of observing it both by direct vision, and also by reflection; an advantage particularly great, as we need not depend upon the spirit-bubble in levelling the instrument, for the observations expose the slightest deviation, and enables us to correct its position; thus:—

Suppose the pole-star, by previous calculation, is ascertained to be at its greatest elongation at a certain time; having set up the instrument approximately level, place an artificial horizon in a proper position to observe the star by reflection: then direct the telescope to the star, and having bisected it with the intersection of the cross-wires, clamp the horizontal circle; now depress the telescope till you see the reflected image of the star in the artificial horizon, which if the instrument is perfectly level, will also appear bisected; if it does not, you must immediately

EXAMPLE.

On February 28, 1834. When the sun had equal altitudes, the azimuth circle read 130° 10′ 15″ and 32° 36′ 15″, therefore the middle point or reading of the approximate meridian was 81° 23′ 15″. The interval of time between the observations was 5 hours, the half of which converted into arc = 37° 30′ 0″. The sun's hourly change of declination = 56″,77, therefore the change for half the interval = 141″,92 (approaching the north pole.) The latitude of the place 51° 28′ 39″, required the correction to be applied to the middle point to obtain the direction of the true meridian.

$\frac{1}{2}(D' - D) = 141'',92$ ......log. $= 2{\cdot}1520436$
Lat. $= 51^\circ\ 28'\ 39''$ ....sec. $= 0{\cdot}2056388$
$\frac{(T' - T)}{2} = 37^\circ\ 30',0$ ....co-sec. $= 0{\cdot}2155529$

Correction $= 374'',31$ ....log. $= 2{\cdot}5732353$
$= 6'\ 14'',31$

		°	′	″
Reading of the middle point	=	81	23	15
Correction	—		6	14,31
Reading of the instrument when set to the true meridian	=	81	17	0,69

Another, and an easy method of finding a meridian line, where pendence can be placed upon the time shown by a chronomer (or watch) is to compute the time of the meridional passage a star near the pole, either above or below the pole, and pointg the telescope of the instrument to the star, bisect it at the act moment; when, if the adjustments of the instrument are rfect, the telescope will be very nearly in the plane of the eridian.

A third method, which admits of great accuracy, when instruents of large dimensions are employed, consists in bisecting a rcumpolar star when at its greatest eastern and western elongions; a line bisecting the horizontal interval, contained beween the two positions of the telescope, will be the direction of the meridian; this interval being measured on the azimuthal circle, and the telescope moved through half that interval, from either its eastern or western position, will place it in the meridian. But it will often be inconvenient to wait till the star attains its second greatest elongation; and as one of the observations must

This value being added to the mean of the times of the observed altitudes, or $\frac{1}{2}$ $(20^h\ 59^m\ 4^s + 27^h\ 0^m\ 40^s) = 23^h\ 59^m\ 52^s$, will give $0^h\ 0^m\ 2^s{,}28$ for the time at apparent noon, to which, if the equation of time be applied, the result will be the time of mean noon.

The equal azimuths may similarly be employed for finding the direction of the true meridian. They must be opposed to each other in pairs, just in the same manner as corresponding altitudes; the first in the morning to the last in the evening, and so of the rest. Then deducting the one from the other, and applying half the difference between the two to the smallest number in each pair, it will give a number of degrees, minutes, and seconds, in which, if all the observations were perfect, the whole six pair would coincide; and if they do not, the fair mean deduced from among them will approach nearly to the truth, *i. e.*, the error of 180° on the azimuth circle from the true meridian.

To that mean point, deduced from these observations, the instrument must now be turned, and fixed there till the proper correction can be applied to it. Upon the telescope being turned down to the horizon each way, it may be observed what distinct object there may be, either to the north or south, that coincides with one of the perpendicular wires; or if no such object should occur, a mark may be placed each way, or either way, to which the instrument may be kept, till the correction can be investigated, which is requisite, on account of the change of the sun's declination during the interval between the morning and evening observations; for any alteration in his declination will affect the azimuth deduced in this way, as it does the hour. This correction is greatest about the time of the equinoxes, as the change in the sun's declination is then the most rapid: it may be computed from the following formula; but when deduced from a star, no such correction is requisite.

$$\text{Correction} = \tfrac{1}{2}\,(D' - D)\ \text{sec. Lat. cosec.}\frac{(T' - T)}{2}$$

In which expression, $(D' - D)$ = the change in the sun's declination during the interval between the observations, and $(T' - T)$ = the interval itself.

Practical Rule. To the log. of half the change of declination, add the log. secant of the latitude, and the log. co-secant of half the interval of time converted into space: the sum — 20 will be the log. of the correction in seconds of space.

When the sun is advancing towards the elevated pole, the middle point, or meridian, as found by equal altitudes, will be too much to the west of the true meridian, by the amount of this to space, and subtract their sum from the log. of the whole interval, *expressed in hours and decimals;* call the remainder A, always *minus.*

To the constant log. 3·1584, add the log. tangent of the above half interval, and subtract their sum from the log. of the whole interval as before, and call the remainder B, *plus,* when the interval is less than twelve hours.

To A, add the log. of double the daily variation of the sun's declination, expressed in seconds, (*minus* when the sun is *receding* from the north,) and the log. tangent of the latitude, (*minus* when south,) the natural number corresponding to the sum to be considered as seconds of time, &c., *plus* or *minus* as it may result.

To B, add the log. of double the daily variation of the sun's declination, as before, and the log. tangent of the sun's declination, *minus* when south, for noon of the given day, the natural number corresponding to the sum, must be taken as seconds of time with its proper sign. The algebraic sum of these two quantities will be the correction required, and must be added to, or subtracted from, the half sum of the times of observation, according as it is *plus* or *minus,* to obtain the correct apparent time.

EXAMPLE.

(*From* Mr. BAILY's *Volume of Astronomical Tables, &c.,* p. 227.)

On July 25, 1823, in N. Lat. 54° 20′ at $8^h\ 59^m\ 4^s$ A.M., and at $3^h\ 0^m\ 40^s$ P.M. the sun had equal altitudes. Required the equation, or correction to be applied to the mean of those times, in order to find the time of noon. The interval of time is $6^h\ 1^m\ 36^s$, which converted into arc = 90° 24′, and by the Nautical Almanac the declination of the sun, at noon on that day, was + 19° 48′ 29″, and its double daily variation equal to − 25′ 29″ = − 1529″. The operation will therefore stand thus:—

Constant log. . =	3·1584	. . . . .	3·1584
$\frac{T}{2}$ = 45° 12′ sin. =	9·8510	. . tangent =	0·0030
Sums . . . =	− 3·0094	. . . . . =	− 3·1614
T = 6·0266 log. =	0·7801	. . . . .	0·7801

down the times of their appulse to each respective horizontal wire, and bringing the preceding or subsequent limb to the corresponding perpendicular one, and reading off the azimuths just as he did before. When all are passed, he may release all the clamps, and replacing his shade, leave the instrument till he has reduced his observations of corresponding altitudes: if he has observed them all, he will have obtained ten pair, and of azimuths six pair, which he must now select from each other, and properly class them, by taking the last in the morning, in conjunction with the first in the evening, and so on, till each observation is paired with its opposite corresponding one."

The time of the meridional passage of the sun's centre, as indicated by the time-keeper employed, will be very nearly equal to half the sum of the times at which each pair of the observations were made, and would be exactly so if the declination did not change during the interval elapsed; (similar observations being made upon any star, the result will show the exact sidereal time of its transit.) The correction to be applied to the time of the sun's transit or apparent noon deduced as above, on account of the change of declination, may be computed by the following formula: *

$$\text{Make } \frac{T}{1440 \sin. \frac{T}{2}} = -A$$

$$\frac{T}{1440 \tan. \frac{T}{2}} = B$$

$$\text{correction} = \mp A \, . \, \delta \, . \tan. L + B \, . \, \delta \, . \tan. D$$

in which L = the latitude of the place (*minus* when south)

δ = the double daily variation in the sun's declination (deduced from the noon of the preceding day, to the noon of the following day; *minus* when the sun is receding from the north)

D = the declination, at the time of noon, on the given day (*minus* when south)

T = the interval of time between the observations expressed in hours.

Note. B is to be considered *plus*, when the interval of time is less than 12 hours, otherwise *minus*.

Practical Rule. To the constant log. 3·1584 add the log. sine of half the interval of time between the observations reduced upper limb arrives at the fourth horizontal one; setting that time down again, and reading off the azimuth again, and setting it down, let him do the same by the fifth wire at each way, and record them as before. He will now find the lower limb of the sun, and its second or following limb, ready for observing in the same way, at the first, second, and third wire, making each perpendicular wire a tangent to the sun's last limb, at the instant that its lower limb just leaves the correspondent horizontal wire; and setting down the time, and after reading off the azimuth, setting that down too under the other. After these, the instrument may be released in azimuth, and the lower limb alone be observed, as it quits the fourth and fifth horizontal wires respectively.

"As soon as the sun has thus passed all his wires, he should read off at both the microscopes the zenith distance and altitude at which he had clamped the vertical circle; and if he has a barometer and thermometer, he should set down their station at the same time; for though he probably will have no occasion to regard the precise altitude at which he made these observations, yet if anything should deprive him of the correspondent ones, he may wish to have it in his power to deduce his time or his azimuth from them, and the reading off the microscopes after all is over is attended with very little trouble.

"These things will appear at first hurrying, and till a person becomes a little accustomed to it they certainly will be so. But after a little practice there will be found time enough to go through the whole with ease; for the vertical circle remains clamped the whole time, and all the six azimuths lie much within the limits of their adjusting screw.

"The easiest method of keeping so many observations from confusion, is to have a slate, or sheet of paper, ready ruled into five columns, to correspond with the five wires in the telescope as they occur in succession, in which to write down the observation belonging to each wire, whether that be time or azimuth; for if any cloud or accident should deprive him of any one or more of his observations, he will then at once see afterwards which of them is missing, when he comes to compare the two sets together.

"Leaving the instrument clamped for altitude, and covered entirely from the sun's rays, he must wait till it is at the same distance from noon in the evening to resume his task. For that, he must hold himself ready against the time comes; and previous to it, he will do well to re-examine the adjustment of his instruabove the horizon, or to an arc of the meridian contained between the zenith and the celestial equator; which arc can readily be determined, by observing the greatest or meridional altitude of a celestial object whose declination at the time is known; for when the declination is greater than the zenith distance, both being of the same denomination, (either both north or both south) the latitude will be equal the declination, *minus* the zenith distance. When the declination and zenith distance are of contrary denominations, then the declination *plus* the zenith distance will be the latitude. And lastly, when the zenith distance is greater than the declination, then the zenith distance *minus* the declination will be the latitude. And always of the same denomination as the greater of the two.

Another method of determining the latitude, is by observing the meridional zenith distance of a circumpolar star, both at its upper and lower culmination; then, computing the refraction for each observation, the co-latitude will be equal to half the sum of the two zenith distances added to half the sum of the two refractions. The latitude thus obtained does not depend on a previous knowledge of the declination of the object observed.

The method of determining the latitude by an observation of the altitude of the pole-star *at any time of the day*, together with the necessary tables, is given in the Nautical Almanac, (as newly arranged.)

A very successful and useful application of this instrument, is the determination of time and the direction of the true meridian, by equal altitudes and azimuths; the method of conducting a series of observations of this kind has been so clearly explained by the late Mr. WOLLASTON, in his *Fasciculus Astronomicus*, that we shall at once transcribe it nearly in the author's own words.

the less will the results depend upon an accurate noting or knowledge of the time.

To compute the Reduction to the Meridian.

Practical Rule. Take from Table VII. the natural versed sines of the hour-angles, or times of each observation from the time of transit separately, and take their mean; then to the log. of this mean, add the log. co-sine of the assumed latitude, the co-sine of the declination, the co-secant of the meridian zenith distance, and the constant log. 9.31443; the sum, rejecting the tens from the index, will be the log. of the reduction in seconds of space.

The meridional zenith distance employed in the computation need only be approximate; if the latitude of the place and the declination of the body be nearly known, the meridional zenith distance will be equal to the difference between the latitude and the declination, when both are north, or both south, but equal to their sum, when one is north and the other south: and the meridian zenith distance of an object below the pole, is equal to the difference between 180°, and the sum of the latitude and declination.

As an example, we shall take that given in Woodhouse's Astronomy, vol. i. page 422, of the star Arcturus, as observed at the Dublin Observatory.

	Face of Inst.	Observed Alt.	Hour Angle in Time.	Versed Sine.
		° ′ ″	m s.	
East of meridian	E.	56 40 5,2	10 35 3	1067
	E.	42 22,9	6 35 3	0413
West of meridian	W.	45 10,0	2 47 7	0074
	W.	43 23,1	7 48 7	0580

Means..........	56 42 45,3	....	533,5	log.	=	2·7271
Reduction .... +	1 52.4		° ′			-
		Latitude......	53 23	cos.	=	9·7756
	56 44 37,7	Declination ...	20 7	cos.	=	9·9727
Refraction	37,8	Mer. Z. D. =	33 16	cos.	=	0·2608
			Constant log.		=	9·3144
Meridian Alt.....	56 43 59,9		′ ″ ″			
		Reduction ..	1 52,4 = 112,4	log.		2.0506

ing the same angle upon different parts of the arc; thus,—After each observation, turn the whole instrument a small quantity on its stand, and adjusting it, again measure the required angle. A fresh set of divisions is thus brought into use at every observation, and the same operation being repeated many times, where great accuracy is required, the mean result may be considered as free from any error that may exist in the graduation. A repeating stand has, of late years, been frequently added to this instrument, and is a most powerful and convenient appendage, when great accuracy is required in the measurement of azimuthal angles. The two opposite micrometers being read off at each observation, will always remove the effect of any error in the centring. The vertical angles should, in all cases, be taken twice, reversing the instrument before taking the second observation, when (as before observed) one of the readings will be an altitude, and the other a zenith distance; the sum of the two readings, therefore, if the observation be made with accuracy, and no error exists in the adjustments or the instrument, will be exactly 90°; and whatever the sum differs from this quantity is double the error of the instrument in altitude, and half this double error is the correction to be applied + or — to either of the separate observations, to obtain the true altitude or zenith distance, + when the sum of the two readings is less than 90°, and — when greater.

In applying the instrument to astronomical purposes, it was formerly the custom to clamp it in the direction of the meridian, and after taking an observation, or series of observations, with the face of the instrument one way, to wait till the next night, or till opportunity permitted, and then take a corresponding series of observations of the same objects, with the face of the instrument in a reversed position. But this method being attended both with uncertainty and inconvenience, it is now usual to complete at once the set of observations, by taking the altitudes in both positions of the instrument as soon as possible after each other. When the meridian altitude is required, several observations may be taken, a short time both before and after the meridional passage; with the face of the instrument in one direction, and with it reversed, noting the time at each observation; and if we have the exact time of the object's transit, its hour angle in time, or its distance from the meridian at the moment of each observation, may be deduced. This, with the latitude of the place (approximately known) and the declination of the object, affords data for computing a quantity called the reduction to the meridian, which added to the mean of the observed altitudes, when the object is above the pole, and be found, the microscope must be moved to or from the circle, by turning the nuts, *g g*, unscrewing one and screwing the other, until the wires and graduations both appear distinct, and no parallax can be detected.

Next, to examine and adjust the *run* (as it is termed) of the screw. If the run has been carefully adjusted by the maker, and no alteration made in the body of the microscope, the image of the space between two of the divisions will be exactly equivalent to five revolutions of the screw, when the wires and divisions are both seen distinctly. Let us, however, suppose that the length of the microscope has been deranged, and that the run is too great; for example, that the space of 5′ on the limb is equal to 5′ 10″ by the micrometer, or that the image is too large. Now the magnitude of the image formed by the object-glass of the microscope, depends entirely on the distance of the object-glass from the limb, and is diminished (in the ordinary construction of the microscope) by increasing the distance between the limb and the object-glass, and *vice versâ*. In the case supposed, the image is too large, therefore the object-glass *h* must be removed further from the limb. Let this be done by turning the screw at *h* in or towards B. The image now will not be formed at *a*, as it ought to be, but nearer to B, and distinct vision must be gained by bringing the whole body of the microscope nearer to the limb. In this way, by two or three attempts cautiously conducted, we shall make five revolutions of the cross-wires correspond exactly with the image of the space between two divisions; and for greater accuracy the 5′ should be read on each side zero, or 10′ on the limb made equal to 10 revolutions of the micrometer.

The screw, *c*′, gives motion to the comb or scale of minutes; and the micrometer-head being adjustable by friction, can be made to read either zero, or any required second, when the cross-wires bisect any particular division, by holding fast the milled-head, *b*, and at the same time turning the divided head, *e e*, round until its zero, or whatever division you require, coincides with the index, *f*: this, it will readily be perceived, is the means of accomplishing the adjustment spoken of at page 96.

Use of the Altitude and Azimuth Instrument.

This is the most generally useful of all instruments for measuring angles, being applicable to geoditical as well as astronomical purposes. In the hands of the surveyor it becomes a to explain the principal parts of the micrometer, the method of adjusting it, and its application to practice. A A, fig. 1, represents the microscope, passing through a collar or support, B, where it is firmly held by the milled nuts, *g g*, acting on a screw cut on the tube of the microscope. These nuts also serve for placing the instrument at the proper distance, for distinct vision, from the divisions it is employed to read. In the body of the microscope, at *a*, the common focus of the object and eye-glasses, are placed two wires, crossing each other diagonally, and they are made to traverse the field of view either up or down, by turning the micrometer-screw, *b*, working in the box, *c c′*. Fig. 2 shows the field of view, with the magnified divisions on the instrument, as seen through the microscope. The shaded part represents the diaphragm, with the cross-wires, the angle made by which, may, by turning the micrometer-screw, *b*, be bisected by any line on the circle in the field of view, as is shown in the figure. On the left hand of the diaphragm appears the comb or scale of minutes, each of the teeth representing one minute. Movable with the wires along the comb is a small index or pointer, *e*, which in the figure is represented at zero, the centre of the scale, as is shown by its bisecting the small hole at the back of the comb. Now one revolution of the screw, *b*, moves the wires and the pointer over one tooth of the comb, that is, over a space equal to one minute; and part of a revolution moves them but a fraction of a minute. To determine this fractional quantity, a large cylindrical head, *e e*, is attached to the screw, having its edge divided into 60 equal parts, representing seconds, the index being fixed opposite the eye of the observer at *f*. In reading off an angle by this instrument, observe first the degree and nearest five minutes shown by the pointer on the graduated circle; then apply to the microscope, and by turning the screw, *b*, in the order of the numbers upon the head *e e*, make the nearest division nicely bisect the acute angles formed by the crossing of the wires; the number of teeth the pointer, *e*, has passed over from zero, to produce such bisection, will be the number of minutes to be added to the degree, &c. read off from the circle and lastly, the odd seconds and tenths to be added, are to b taken from the divided head, *e e*, as shown by the index, *f*.

The adjustments of the microscope, consist in making t cross-wires in its focus, and the divisions on the circle, bo appear at the same time distinct, and free from parallax; a also making five revolutions of the screw, exactly measur inute space on the graduated circle. For the forme the eye-piece, *d*, until distinct vi justed by their proper screws, so as to show that mean. This process may be repeated for obtaining a greater degree of accuracy; but its final determination should be deduced from observations upon many heavenly bodies, and the minute error that may remain unadjusted had better be allowed for." This and the preceding operation may be more conveniently performed by a collimating telescope.

The adjustment for setting the cross-wires truly vertical, is the same as that described as belonging to the portable transit; the position of the horizontal wires will then depend on the maker, or the horizontal wire may be put right by making it thread an equatorial star at its transit, when the vertical wires will depend upon the maker.

In conclusion it may be observed, that during a series of observations, if the instrument should be detected to be a small quantity out of level, (having previously gone through the principal adjustments,) it may generally be restored by means of the foot-screws only, when they require but a slight touch to effect it: this is more especially essential when the level of the horizontal axis is the one deranged, as correcting it by moving the Y's would derange the adjustment of the vertical circle with regard to its reading microscopes, the construction and adjustments of which it will next be necessary to describe.

The error of the vertical axis is to be detected by the hanging level, and can very readily be allowed for in computing the observation: as a general rule, when great accuracy is required, it is easier and safer to adjust by computation than by mechanical contrivances.

THE READING MICROSCOPE.

Fig. 1.

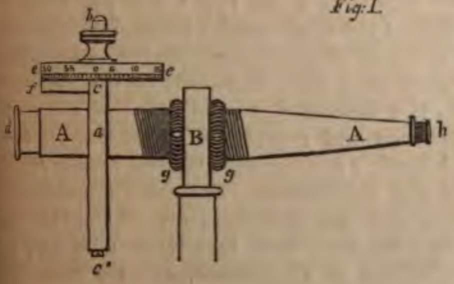
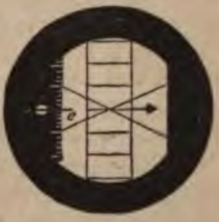


Fig. 2.



The divisions on the graduated circle indicate spaces of five minutes each, which are read off along with the *degree*, by means the air-bubble will steadily remain in the middle of the level during an entire revolution of the instrument in azimuth. These adjustments should be first performed approximately, for if the third foot-screw is much out of the level, it will be impossible to get the other two right. The vertical axis is now adjusted.

The next adjustment is to set the vertical circle at such a height that its two reading microscopes shall be directed to two opposite points in its horizontal diameter, which is done by raising or lowering the Y's which carry the horizontal axis.

The next adjustment is the levelling of the horizontal axis by means of the striding-level, the whole of which operation is in all respects the same as that described for levelling the transit axis, to which therefore the reader is referred. After performing this, the preceding adjustment must be examined, as it will probably be deranged. Indeed it is better first to set the axis horizontal, and then, by equally raising or depressing the two ends, to bring the miscroscopes into a diameter, and finally level again.

The adjustment for the line of collimation requires not only that the middle vertical wire shall describe a great circle, but that the middle horizontal wire shall have a definite position with respect to the divisions of the limb. It is usual to rectify the position of one of these at a time, taking the middle vertical wire first.* The error of this wire is ascertained and corrected, precisely in the same manner as that of the transit-instrument; with this difference, that, instead of taking the axis out of its bearings and turning it end for end, the whole instrument is turned half round in azimuth, which is an equivalent operation. The middle horizontal wire may be adjusted in the following manner: "Point the telescope to a very distant object, bisect it by the middle horizontal wire (near the intersection of the wires,) and read off by the microscopes the apparent zenith distance; now reverse the instrument in azimuth, and turning the telescope again upon the same object, bisect it as before, and again read off the angle which they show. One of these angles will be an altitude, and the other a zenith distance;" and, if there is no error, the sum of the two readings will be 90°, and half of what it differs from 90° will be the error of collimation, which may be either applied to correct any observation made during its existence, or removed in the following manner. One of the readings being the zenith distance, and the other the altitude of the object, reduce the zenith distance to an altitude, or *vice versâ*, and take the mean; it is evident that "the mean of the two will be the true zenith distance or altitude respectively; and whil the telescope bisects the object, the microscopes must be ad set it up in its place, and must be removed as soon as the operation of levelling the horizontal axis is performed. The whole instrument stands upon three foot-screws, placed at the extremities of the three branches which form the tripod,* and brass cups are placed under the spherical ends of the foot-screws. A stone pedestal, set perfectly steady, is the best support for this as well as the portable transit-instrument.

Of the Adjustments.

The first adjustment to be attended to, after setting the instrument up in the place where the observations are to be made, is to set the azimuthal or vertical axis truly perpendicular to the horizon: the method of doing this is to turn the instrument about, until the spirit-level, P, is lengthwise in the direction of two of the foot-screws, when by their motion the spirit-bubble must be brought to occupy the middle of the glass-tube, which will be shown by the divisions on the scale attached to the level. Having done this, turn the instrument half round in azimuth, and if the axis is truly perpendicular, the bubble will again settle in the middle of the tube; but if not, the amount of deviation will show double the quantity by which the axis deviates from the vertical in the direction of the level; this error must be corrected, one half by means of the two foot-screws (in question,) and the other half by raising or lowering the spirit-level itself, which is done by the screw represented at *f*. The above process of reversion and levelling should be repeated, to ascertain if the adjustment has been correctly performed; for, as we before observed, when speaking of the transit-instrument, adjustments of every kind can be made perfect only by successive trials and approximations.

Next turn the instrument round in azimuth a quarter of a circle, so that the level, P, shall be at right angles to its former position; it will then be over the third foot-screw, which may be turned until the air-bubble is again central, if not already so, and this adjustment will be completed: if delicately performed, are carried by two arms bent upwards near their extremitie and attached towards the top of one of the pillars. The projec ing arms are shown at N, and the microscopes above at O.

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* The foot-screws are sometimes made in the following ingenious manner, as described by Mr. TROUGHTON, in the Memoirs of the Astronomical Society, vol. i. p. 37. "Each of the three screws is double, that is, a screw within a screw: the exterior one, as usual, has its female in the end of the tripod, and the female of the interior screw is within the exterior; the interior one is longer than the other, its flat end rests on a small cup on the top of the support, and its milled head is a little above the other. Now by this arrangement we gain three distinct motions: for by turning both screws together, an effect is produced equal to the natural range of the exterior screw; by turning the interior one alone the

A diaphragm, or pierced plate, is fixed in the principal focu of the telescope, on which are stretched five vertical and fiv horizontal wires: the intersection of the two centre ones, deno ing the optical axis of the telescope, is the point with which terrestrial object is bisected, when observing angles for geodetic purposes. The vertical wires are used for the same purpose those in the transit telescope, and the horizontal ones for takin altitudes of celestial objects. A micrometer having a movabl wire is sometimes attached to the eye-end of the telescope, bu it is not generally applied to instruments of portable dimension The illumination of the wires at night is by a lamp, supporte near the top of one of the pillars, as at *d*, and placed opposi the end of one of the pivots of the axis, which being perforate admits the rays of light to the centre of the telescope-tub where falling on a diagonal reflector, they are reflected to th eye, and illuminate the field of view: the whole of this contri ance is precisely similar to that described as belonging to th transit-instrument.

The vertical circle is usually divided into four quadrants, eac numbered, 1°, 2°, 3°, &c., up to 90°, and following one anoth in the same order of succession; consequently, in one positio of the instrument, altitudes are read off, and with the face of th instrument reversed, zenith distances; and an observation is no to be considered complete, till the object has been observed i both positions. The sum of the two readings will always be 90 if there be no error in the adjustments, in the circle itself, or i the observations.

It is necessary that the microscopes, O O, and the centre o the circle, should occupy the line of its horizontal diameter; to effect which, the up-and-down motion (before spoken of) by means of the screws, *b b*, is given to the Y's to raise or lower them, until this adjustment is accomplished. A spirit-level, P, is suspended from the arms which carry the microscopes: this shows when the vertical axis is set perpendicular to the horizon. A scale, usually showing seconds, is placed along the glass-tube of the level, which exhibits the amount, *if any*, of the inclination of the vertical axis. This should be noticed repeatedly whilst making a series of observations, to ascertain if any change has taken place in the position of the instrument after its adjustments have been completed. One of the points of suspension of the level is movable, up or down, by means of the screw, To the centre of the tripod, A A, is fixed the vertical axis of the instrument, of a length equal to about the radius of the circle; it is concealed from view by the exterior cone, B. On the lower part of the axis, and in close contact with the tripod, is centred the azimuth circle, C, which admits of a horizontal circular motion of about three degrees, for the purpose of bringing its zero exactly in the meridian; this is effected by a slow-moving screw, the milled head of which is shown at D. This motion should, however, be omitted in instruments destined for exact work, as the bringing the zero into the meridian is not requisite, either in astronomy or surveying; it is in fact purchasing a convenience too dearly, by introducing a source of error not always trivial. Above the azimuth circle, and concentric with it, is placed a strong circular plate, E, which carries the whole of the upper works, and also a pointer, to show the degree and nearest five minutes to be read off on the azimuth circle; the remaining minutes and seconds being obtained by means of the two reading microscopes, F and G: this plate, by means of the conical part B, (which is carefully fitted to the axis) rests on the axis, and moves concentrically with it. The conical pillars H H, support the horizontal or transit axis, I, which being longer than the distance between the centres of the pillars, the projecting pieces, *c c*, fixed to their top, are required to carry out the Y's, *a a*, to the proper distance, for the reception of the pivots of the axis; the Y's are capable of being raised or lowered in their sockets by means of the milled-headed screws, *b b*, for a purpose hereafter to be explained. The weight of the axis, with the load it carries, is prevented from pressing too heavily on its bearings, by two friction rollers on which it rests, one of which is shown at *e*. A spiral spring, fixed in the body of each pillar, presses the rollers upwards, with a force nearly a counterpoise to the superincumbent weight; the rollers on receiving the axis yield to the pressure, and allow the pivots to find their proper bearings in the Y's, relieving them, however, from a great portion of the weight.

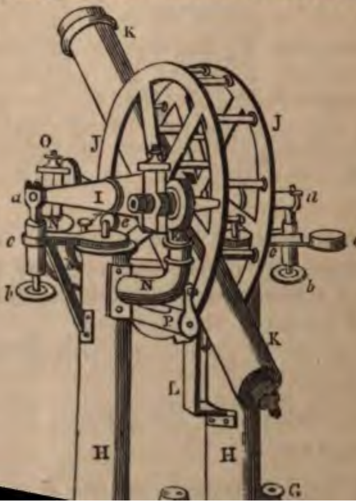
on various nights, the telescope should be reversed. With these precautions, and a level of the best kind, the latitude may be obtained within a second or two, if the place of the star is sufficiently well known; and *differences* of latitude, whether the star be known or not.

To find the time when the star will come to the proper position for observation, viz., the prime vertical; first ascertain when the star will be on the meridian, by the method explained at page 82, then, by the following formula compute the time that would elapse during the passage of the star from the prime vertical to the meridian, or (referring to the above diagram) the angle, S P Z, which *time*, subtracted from that of the meridian passage, will give the time of the star's being on the prime vertical, or in the required position for making the first observation.

Formula, cos. S P Z (or Δ'') = tan. P.Z, cot. P S.

Practical Rule. To the log. tangent of the assumed co-latitude add the log. co-tangent of the star's polar distance, the sum will be the log. co-sine of half the elapsed time in arc, which divided by 15 will give the time required.

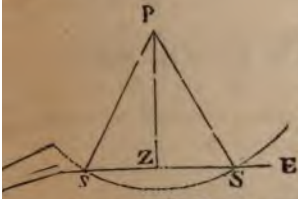
THE ALTITUDE AND AZIMUTH INSTRUMENT.



which can only be the case when she is near the full at the time of transit, a better result can be obtained.

There is a mode of finding the latitude by the transit-instrument, pointed out by Professor Bessel, and used with great success in the Russian survey, which we will now explain in some detail, as the method is not so commonly known or practised in this country as it deserves to be.

Place the transit-instrument with its supports north and south, so that the telescope when pointed to the horizon looks due east and west. Observe the passage of a well-known star over the middle wire when the telescope is pointing east, and again, observe the passage of the same star over the middle wire when the telescope is pointing west, noting the time carefully. The star should be near the zenith, (such a star as γ Draconis, for instance, in the latitude of London, and for a degree or two to the northwards,) as the observations take less time, and are therefore more independent of the timekeeper employed; the method is also more accurate when the star is near the zenith than when otherwise.



In the accompanying figure, P is the pole, Z the zenith, E Z W the prime vertical passing through the east and west points, the dotted line S s the path of the star; all seen as projected on the horizon from a point above Z. Then in the right-angled spherical triangle, P Z S, P S is the north polar distance of the star, P Z the co-latitude, and the angle Z P S, half the time elapsed from S to s, therefore, tan. P Z = tan. P S × · cos. Z P S.

Let $\Delta'' =$ half the interval in time reduced to arc between the two transits of the star over the prime vertical, (a circle which passes through the zenith, and east and west points of the horizon.)

$\pi =$ the N. P. D. of the star (taken from the Nautical Almanac.)

$\lambda =$ the co-latitude of the place.

then $\tan. \lambda = \tan. \pi \cos. \Delta''$

or in words — to the log. tangent of the star's N.P.D. add the log. co-sine of half the time elapsed, and the sum — 10 will be the log. tangent of the co-latitude required.

	Diff. Intervals.
	·52
	·73
	·71
	·62
Mean . . .	·65

On December 8th, 1834, the moon passed the meridian of Greenwich at 6^h 40^m, the declination being then about 7°, and it would be about one thousandth of a degree different at Cambridge; and the 1000dth part of ·134 (the number corresponding to 7° of declination in Table XII.) is too small a quantity to be worth attention. This also is the case with the effect of the change in the moon's semidiameter, the change being not more than a thousandth of a second of space; and the effect of that small change on the time of the moon's transit being clearly beyond the reach of notice in ordinary observers. The Nautical Almanac gives the following:—

	M. S.
Hourly change of ☽'s R.A, from 5 hours to 6 .	1 50, 19
„ „ 6 „ 7 .	1 50, 03
„ „ 7 „ 8 .	1 49, 87

Hence, at 6^h 40^m the hourly rate of change would be about 1^m 50^s,08.

M. S.		
1 50,08	Table V.	1·502334
,65	log.	= 9·812913
Longitude of Cambridge in time 21^s, 3		1·315247

The longitude of the Cambridge Observatory has been determined by Professor AIRY to be 23^s, 5. The reader may perhaps be surprised, that the above result differs 2^s, 8 from it; but it may be remarked, that by this method of finding longitude, it is absolutely necessary, that a great number of results be taken as a satisfactory determination. This arises mostly from the errors made in observing the transit of the moon's limb, which, it is well known to practical men, is a very difficult observation to make correctly; and a very small error in the observation makes a considerable one in the final result: supposing the transits of the stars to have been observed *perfectly* correct, yet, if an error of only two tenths of a second be made in that of the moon's limb at either Observatory, the longitude dedu or, if more than one star has been observed, call the seconds in the mean of the differences of the corresponding intervals A.

If either of the intervals be in mean time, add to it its 360th part diminished by the 70th part of itself, and the sum will be the corresponding interval in sidereal time. And if both are in mean time, reduce their difference to sidereal time by the same rule. Table IV. may also be used for this purpose.

If the moon precede the star at the easterly, and follow it at the westerly meridian, the *sum* of the intervals instead of the *difference* will be A.

Then *add* the *logarithm of the seconds in* A, the difference of the *sidereal intervals* to the *logarithm* from *Table V.*, and the sum will be the *logarithm* of the difference of longitude in *seconds of time.*

Note. The parts for hundredths in Table V. are found in the column of 'parts' opposite the corresponding tenths. Thus, for $1^m 42^s,57$, the log. for $1^m 42^s,5$, is 1·534256, and the part for seven hundredths is 304—whence the log. is 1·533952. Striking off the figures on the right, in the column of 'parts,' the remaining figures on the left are parts for thousandths.

EXAMPLE.

December 8th, 1834.

Star, &c.	Clock Transit, observed at Greenwich.	Rate of Clock.	Clock Transit, observed at Cambridge.	Rate of Clock.
	H. M. S.	S.	H. M. S.	S.
96 Aquarii ..	23 10 58,18	— 0,68	23 10 14,40	— 2,56
Piscium ..	23 39 35,32		23 38 51,72	
☽'s 1st Limb	23 47 29,86		23 46 45,52	
Piscium ..	23 57 1,18		23 56 17,53	
Ceti	0 21 45,08		0 21 1,32	

First find the mean intervals between the passage of the stars d the moon at both places, thus :—

Greenwich Intervals.		Cambridge Intervals.	
M.	S.	M.	S.
36	31,68	36	31,12
6	54,54	7	53,80
9	31,32	9	32,01
34	15,22	34	15,80

Intervals corrected for Rate.

36	31,70	36	31,18

PRACTICAL RULE.

To the estimated longitude in time, add the correction from Table XI., and apply the sum to the time of the moon's passing the meridian of Greenwich, as given in the Nautical Almanac, adding if the longitude is *west*, or subtracting it if east; and the sum or the remainder will be the approximate Greenwich date for the moon's passing the given meridian.

Find the moon's right ascension, both for this time and the time of her passing the meridian of Greenwich, and divide the difference of her right ascensions by the hours, &c., in the difference of these times, and the quotient will be the mean hourly change of the moon's right ascension in the interval, which is the argument of Table V.

Take also the declinations roughly for the same two times.

With the mean of these declinations, and the change of the moon's semidiameter, take the correction from Table VI. and apply it to the interval between the transits of the star and the moon's bright limb, as observed at or computed for the more westerly meridian.

Again, with the mean of the declinations take the corrections from Table XII., and multiplying it by the degrees in the moon's change of declination, apply the product as a second correction to the western interval.

The following formula will show the signs with which these corrections are to be applied.

Sign of First Correction.

	Moon.	Limb Obsd.	Correct.
Moon's semidiam. increasing	preceding star	W	—
		E	+
	following star	W	+
		E	—

	Moon.	Limb Obsd.	Correct.
Moon's semidiam. decreasing	preceding star	W	+
		E	—
	following star	W	—
		E	+

Sign of Second Correction.

	Moon.	Limb Obsd.	Correct.
Moon's declination increasing	preceding star	W	+
		E	—
	following star	W	—
		E	+

	Moon.	Limb Obsd.	Correct.
Moon's declination decreasing	preceding star	W	—
		E	+
	following star	W	+
		E	—

correctly as if the instrument had been in a state of perfect justment when the observation was made.

	H.	M.	S.
Observed time of transit.. .. .. =	14	35	4,860
Correction for the collimation .. =	+		0,904
„ „ level.. .. .. =	—		1,811
„ in azimuth .. .. .. =	—		2,157
Corrected observation...... =	14	35	1,796
Computed right ascension ... =	14	37	28,910
Clock slow on sidereal time . =		2	27,114

Besides the determination of time, the portable transit-instrument may be successfully employed in determining the longitude. he Nautical Almanac contains, for each lunation, a list of the ght ascensions and declinations of the moon-culminating stars, hose meridional transits being observed, together with that of ie moon, at any two places, the differences of right ascension ius obtained between the moon's illuminated limb and each of iose stars, form the data required for computation. "If the oon had no motion, the difference of her right ascension from iat of a star would be the same at all meridians, but in the in-rval of her transit over two different meridians, her right as-nsion varies, and the difference between the two compared dif-rences exhibits the amount of this variation, which, added to ie difference of meridians, shows the angle through which the esterly meridian must revolve before it comes up with the ioon; hence, knowing the rate of her increase in right ascen-ion, the difference of longitude is easily obtained."

The necessity of having recourse to actual observation of the ame stars at the two places, in order to obtain the longitude, nay soon be dispensed with, since their apparent right ascensions are given in the Nautical Almanac. At present, however, and until the places of the moon-culminating stars are perfectly well known, corresponding observations are required for the accurate determination of differences of longitude.

The difference of longitude between the stations, is supposed to be approximately known, or may be got near enough for an approximation, by dividing the difference between the observed and computed right ascension of the moon's bright limb by the hourly motion given in the Nautical Almanac.

The formula for computation, with the necessary explanation, may be found in the Memoirs of the Royal Astronomical So-in which a = the factor for azimuthal deviation, + when the instrument deviates to the eastward of the south meridian.

π = the polar distance of the star.
λ = the co-latitude of the place.

This formula in words gives the following:—

Rule.—To the log. of the factor for azimuthal deviation, add the co-secant of the polar distance, and the sine of the difference between the polar distance and co-latitude: the sum will be the log. of the correction required.

As an example, let us take the star ϵ Bootis. (Pearson's Astron. vol. ii. p. 344.)

H. M. S.
Observed time of transit . . . . = 14 35 4, 86

Error of collimation . . 12″ or = + 0, 80
Inclination of the axis . . . . . = — 1, 75
Deviation of Instrument in azimuth . = — 4,737

The errors are in units, each of which = 15″

° ′
Polar distance . . . . = 62 12
Co-latitude . . . . = 38 27

The correction for the Collimation.

Deviation = + 0,80 log. . . . = + 9·90309
Polar dist. 62° 12′ co-secant . . . = + 0·05326

Correction = + 0^{s},904 . log. = + 9·95635

The correction for the Level.

Deviation = — 1,75 log. . . . = — 0·24304
Polar dist. 62° 12′ co-secant . . . = + 0·05326
Polar dist. minus co-lat. 23° 45′ cos. . = + 9·96157

Correction = — 1^{s},811 . log. = — 0·25787

The Correction in Azimuth.

Deviation = — 4,737 log... .. .. = — 0·67550
Polar dist. 62° 12′ co-secant .. .. = + 0·05326
Polar dist. minus co-lat. = 23° 45′ sine = + 9·60508

Readings of the Scale.

East End.		West End.
"		"
109,0	. . . .	69,6
109,0	. . . .	69,8
108,8	. . . .	69,9
	Level Reversed.	
69,0	. . . .	109,0
68,6	. . . .	108,9
69,1	. . . .	109,0
533,5	Sums	536,2
		533,5

e by the number of observations, 12) 2,7

$\frac{1}{2}$ difference = 0,23 = the amount iation in arc, showing that the west end of the axis is by that quantity than the east end, since the sum of the readings is greater than the sum of the eastern. This y, divided by 15, will give the proper factor for inclin- It is more convenient that the scale should be divided its, each of which is 15″.

g in this manner determined the inclination of the axis evel, the correction to be applied to the time of observ- any star made during the existence of that error, may ted from the following formula :—

$$\text{Correction} = b \cos. (\pi - \lambda) \text{ co sec. } \pi$$

e factor for the inclination of the axis + if the west end be too high.

polar distance of the star.

co-latitude of the place.

nula in words gives the following practical rule. To the factor for inclination of the axis, add the log. the polar distance, and the log. co-sine of the dif- veen the polar distance and the co-latitude : the sum the log. of the correction in time required.

already explained the manner of ascertaining the viation of the instrument from the rections, that persons possessing transit-instruments may adop which method they think proper.

The first correction is for the deviation of the line of collimation : the amount of the error may be determined by a micrometer attached to the eye-end of the telescope, by which, whe the telescope is directed towards any distant object, the angula distance of that object from the central wire is measured in revolutions and parts of the micrometer-screw. The instrument i then reversed, and the distance of the same object from the central wire again measured, when half the difference of the measure is the error in collimation; and the angular value of a revolutio of the screw being known, the corresponding value of the erro is likewise known. The correction on account of this error t be applied to the time of each observation may be compute from the following formula :—

$$\text{Correction} = \frac{c}{15} \text{ co-sec. } \pi$$

c = the error of collimation + if the deviation is toward the east.

π = (as before) the polar distance of the star.

Hence we have in words this rule : To the log. of the deviation in collimation, add the log. co-secant of the polar distance of the star, and the arithmetical complement of the log. of 15: the sum will be the log. of the correction in time required.

The next correction to be considered, is that arising from a want of horizontality in the axis. The spirit-level, which we described as striding across the instrument and resting on the pivots, determines the amount of the inclination of the axis, and also, as we have seen, enables the observer to correct it. Above the glass tube, and parallel to its length, is placed a fine graduated scale, the reading of which points out the number of seconds in arc that the pivots deviate from the true level, shown by the air-bubble receding from the centre towards that pivot which the highest; but as it is necessary, when correcting for the justment, to remove half the error, by giving motion to little screw on the level itself, so, for the same reason, in the measurement of the error, it is necessary to reverse the on the axis, and read the scale at each extremity of the bubble in both its positions; that is, with the same end of level on both the east and west pivots alternately,—and the ference of the sums of the two readings divided by the of readings will be the amount of deviation. This may illustrated by the following example, in which the

Table III. will not answer for performing the reverse operation, viz., converting a portion of mean solar time into a corresponding portion of sidereal time; Table IV. must be employed for this purpose, adding to the given portion of mean time the quantity taken from the table corresponding thereto, and the sum will be an equivalent portion of sidereal time. As an example we will take the above case of Capella.

		H.	M.	S.
Mean time		5	21	16,87
Table IV.	+			52,78
Sidereal interval		5	22	9,65
Sidereal time at mean noon		23	42	15,64
		29	4	25,29
	—	24		
Sidereal time of the star's passage, or its right ascension		5	4	25,29

The method of taking out the correction from Table IV. is exactly similar to that given in the above example for Table III.

To find the error of a clock or chronometer intended to show mean time from an observed transit of the sun, nothing more is necessary than to apply the equation of time to 24 hours, and the difference between the result and the time of the sun's transit, as shown by the chronometer, is the error of the chronometer for mean time; + when the chronometer time is the greater, and — when it is the less.

From the description which has been given of the method of bringing a transit-instrument into a state of perfect adjustment, it might be inferred that it is essential it should be strictly so, to obtain accurate results from the use of it. It is certainly desirable that the adjustments should be examined and rectified as often as possible, as doing so ultimately saves the labour of computing the corrections to be applied to each observation, on account of the errors in the position of the instrument. But in some established observatories, where large instruments are employed, it is not attempted to put them in perfect adjustment, but the amount of the various derangements is ascertained from time to time, and the observations corrected accordingly. The adoption of this method, with so small an instrument as the one which we have been describing, where the adjustments are easily examined and corrected, will give indeed more accurate results, bably be a very accurate determination of the error for the mea of the times at which the observations were made. In lik manner the mean daily rate may be found by taking the difference between the errors as determined by the same object fro day to day; and if more than one day has elapsed between th observations, dividing the change in the error by the number o days elapsed; the rate, when the clock is too fast, will be + (o gaining) when the second error is greater than the first, and - (or losing) when the second error is the least; and *vice vers* when the clock is too slow.

When a clock or chronometer, showing mean solar time, i employed, its error from such time may be found, by computin the mean time of the passage of the object over the meridian o the place, and the difference between such mean time, and th observed time of the object's meridian passage, will, as befor be the error of the clock from mean time.

The following is the method of computing the mean solar tim of the transit of a star across the meridian.

From the right ascension of the star, subtract the sidere time at mean noon for the given day, taken from the Nautic Almanac, (adding 24 hours to the former when the latter excee it) the remainder is the sidereal interval after noon of that da From this, subtract the acceleration of sidereal upon mean tim and the result is the required mean solar time of the passag As an example, suppose it were required to find the mean ti of the passage of Capella on March 18th, 1834:

		H.	M.	S.
Right ascension of Capella (+ 24 hours)		29	4	25,29
Sidereal time at mean noon		23	42	15,64
Sidereal interval, past noon	=	5	22	9,6
Acceleration of sidereal on mean time for the interval	=	—		52,7
Mean time of passage	=	5	21	16,8

The acceleration of sidereal on mean time is to be taken Table III.; thus, in the above example:

		M.	S.
Acceleration for 5 hours		0	49,148
„ 22 minutes			3,604
„ 9 seconds			0,025
„ 65 hundredths . . .			0,003
For the whole interval	=	0	52,780

difference from the centre wire, to obtain a correct mean; the correction to be applied to the mean of the wires may be computed as follows: divide the difference between the sum of the first two and sum of the last two equatorial intervals by 5, and to the log. of the quotient add the log. co-secant of the polar distance of the star; the sum will be the log. of the correction required, *plus* if the sum of the two first intervals is greater than the second, otherwise *minus*. Such inequality in the intervals should never be allowed to remain, unless circumstances prevented their rectification.

In regular observatories, the transit-instrument is employed, not only for the determination of time, but in forming catalogues of the right ascensions of the fixed stars, and other important operations in astronomy; purposes for which instruments of a superior class, and fixed in their respective places, are required. But, from the small size and low optical power of the portable transit-instrument, it can be applied with good effect only to the determination of time, and of the longitude by observations of the moon and moon-culminating stars. The Nautical Almanac contains the true apparent right ascension of the sun, and of one hundred of the principal fixed stars; that is, the sidereal time when each of them, respectively, is on the meridian, or on the centre wire of a properly adjusted transit-instrument; and if the instant when a star so passes the central wire, be noted by a clock correctly adjusted to sidereal time, the time shown by the clock will be the right ascension of the star as given in the Almanac. The difference therefore between the time shown by a clock, and such right ascension, will be the error of the clock from sidereal time + (or too fast) when the clock time is greater than the right ascension, and — (or too slow) when it is less. Thus, on March 18th, 1834, (page 79,)

	H.	M.	S.
The observed passage of Capella by clock . .	5	5	6,60
Right ascension by Naut. Alm.	5	4	25,29
Clock error . . . . +	0		41,31

In the same manner the error of the clock is deduced from an observed transit of the sun's centre, the time of which, as before shown, is derived from a mean of the observations of the first and second limbs; but when, from intervening clouds or other circumstances, one limb only can be observed, the passage of the centre may be found, by adding or subtracting *the sidereal time of the sun's semidiameter passing the meridian*, as given in the Nautical Almanac, according as the first or second limb may the first, third, and last; and the second limb over the second and fourth; which being reduced in the same manner as the observation of the sun, will give the meridional passage of the centre. When an observation at one or more of the wires has been lost, it is impossible to take the mean in the same way as in a perfect observation. If the centre wire is the one that is deficient, the mean of the other four may be taken as the time of the meridional passage, or the mean of any two equally distant on each side of the centre, (supposing the interval of the wires to be equal;) but when any of the side wires are lost, and indeed under any circumstance of deficiency in the observation, the most correct method of proceeding is as follows: By a considerable number of careful observations over all the wires, the equatorial interval between each side wire and the centre one is to be deduced and set down for future use. Then, when part of the wires only are observed, each wire is to be reduced to the mean, by adding or subtracting, as the case may be, to the time of observation, the equatorial interval between that wire and the centre wire, multiplied by the secant of the declination of the star, as in the following rule.

To the log. of the equatorial interval (from the wire at which the observation was made to the centre) add the log. secant of the star's declination (or co-sec. of its polar distance,) the sum, rejecting ten from the index, will be the log. of the interval from the wire at which the transit was taken, to the centre wire, which being added to observations made at the first or second wire, or subtracted from those made at the fourth or fifth, will give the time of the star's passing the meridional wire.

The equatorial intervals of the wires may readily be computed by the following rule, from observations made upon any star whose declination is known. To the log. of the interval occupied by the star in passing from any wire to the centre wire, add the log. cosine of the star's declination (or sine of its polar distance;) the sum, rejecting ten from the index, will be the log. of the equatorial interval, which being determined for each wire, from observations of a number of stars having different declinations, the mean will be a very correct result. The equatorial intervals of the wires of the transit at the Royal Observatory, were found to be,

s.
From the first wire to the third = 36,647
" second " = 18,305

at another; thus destroying each other's effect, the mean result will come out very nearly the same as the observation at the middle wire, if they are made with any tolerable degree of accuracy, and if the intervals of the wires are uniform.

Example of the Greenwich mode of registering Transit Observations.

Illuminated End—East.					Mean of Wires.	Clock.		No. of Days.	Object.
I.	II.	Merid. Wire	IV.	V.		Error.	Rate.		
s.	s.	M. s.	s.	s.	H. M. s.	M. s.	s.		
36,1	54,4	50 12,7	31,1	49,5	23 50 12,76	: :	: :	: :	⊙ 1 Limb.
45,2	3,5	52 21,9	40,3	58,6	23 52 21,90	: :	: :	: :	⊙ 2 Limb.
: :	: :	: :	: :	: :	23 51 17,33	+0 41,32	+0,01	4	⊙ Centre.
14,1	40,5	5 6,6	32,7	59,1	5 5 6,60	+0 41,31	+0,05	3	Capella.
: :	: :	20 59,0	: :	: :	6 20 59,00	: :	: :	: :	Cephei 51 *Hev.*
: :	: :	26 32,5	: :	: :	6 26 32,50	: :	: :	: :	δ Urs. Min. S.P.
52,6	11,8	38 30,7	50,1	9,2	6 38 30,88	+0 41,13	0,00	3	Sirius.

The annexed Table is an example of the Greenwich mode of registering observations made with a transit-instrument.

The heading at the top of the columns sufficiently explains the nature of their contents. The error of the clock from sidereal time is obtained, by taking the difference between the mean of the wires, and the apparent right ascension of the object as given in the Nautical Almanac; and the daily rate is the difference of such errors, divided by the number of days elapsed between the observations. In observing the sun, the times of passing of both the first and second limb over the wires are observed and set down as distinct observations, the mean of which gives the time of the passage of the centre across the meridian, as is shown in the annexed example. The wires of the instrument are generally placed by the maker at such a distance from each other, that the first limb of the sun shall have passed all of them before the second limb arrives at the first, and the observer can thus take the observations without hurry or confusion.

One limb only of the moon can be observed, except when her transit happens to be within an hour or two of her opposition; and in observing the larger adding to the difference of the observed times, the acceleratio of the fixed stars for that interval, (Table IV.,) which will co vert that portion of *mean* into an equivalent portion of *sidere time;* so that by means of this correction it will be indiffere whether the clock shows sidereal or mean time.

" If, before or after the passage of the stars, the telescope b pointed to the horizon and compared with some object there, meridian mark may be set up, which may be corrected from ti to time by subsequent observations on various stars similarl situated, and when once *correctly* fixed, it will serve to veri both the meridional position of the instrument, and the adjus ment of the collimation."

Having, by means of the previous adjustments, made the li of collimation describe a great circle passing through the zenit of the place, and the north and south points of the horizon, th instrument will be in a fit state for making observations. W have said that the telescope contains five vertical and two hor zontal wires, placed a short distance from each other; these la are intended to guide the observer in bringing the object to pa across the middle of the field, by moving the telescope until i appears between them: the centre vertical is the meridiona wire, and the instant of a star's passing it will be the time o such star's being on the meridian; but as, in noting the time, it will not often happen that an exact second will be shown by the clock, when the star is bisected by the wire, but it will pass the wire in the interval between two successive seconds, the observer must, therefore, whilst watching the star, listen to the beats of his clock, and count the seconds as they elapse; he will then be able to notice the space passed over by the star in every second, and consequently its distance from the wire at the second before it arrives at, and the next second after it has passed it, and with a little practice he will be able to estimate the fraction of a second at which the star was on the wire, to be added to the previous second: thus, suppose the observer counted 4, 5, 6, 7, 8 seconds, whilst watching the passage of a star, which passed the wire between the 7th and 8th, at which times it appeared equally distant on each side of it, the time of the transit would then be $7^s,5$; but if it appeared more distant on one side than the other, it would be $7^s,3$, or $7^s,7$, &c., according to its apparent relative distance from the wire.

This kind of observation must be made at each of the five wires, and a mean of the whole taken, which will represent the time of the star's passage over the mean or meridional wire. The utility of having five wires instead of the central one only will be readily understood from the consideration that a mean result higher and lower stars, and L, as before, the latitude of the place of observation.

This formula, in words, gives the following rule: To the log. of the difference of times *minus* the difference of right ascensions, add the log. sin. of the polar distance of the higher star, the log. sin. of the polar distance of the lower star, the log. co-secant of the difference or sum of the polar distances of both the stars, (the difference when they are both above the pole, and the sum when one is above and the other below the pole,) and the log. secant of the latitude: the sum will be the log. of the azimuthal deviation, which multiplied by 15 will be the deviation in arc.

As a complete example, let us take a high and low star, from the same day's work at Greenwich that we took our former example from, and see how nearly alike the deviation comes out by the two calculations.

March 18th, 1834. (See page 79.)

	Observed Time.		Apparent A.R. from Naut. Alm.
	H. M. S.		H. M. S.
Higher star, Cephei 51 *Hev.*	6 20 59,00	...	6 20 19,61
Lower ,, Sirius	6 38 30,88	...	6 37 49,76
Difference............ =	— 17 31,88	..	— 17 30,15
Subtract diff. of A.R. .. =	— 17 30,15		

— 1,73 = the difference of time *minus* the difference of right ascension, which being — shows that the deviation is to the west of south, agreeing with our former determination, (page 75) viz., east of north. Let us now compute the deviation in azimuth by our last formula, and see how nearly they agree.

Difference of intervals	$1^s,73$ ..	log. ..	0·23805
π the P.D. of Cephei	2° 43′ 50″ ..	sine ..	8·67796
π' ,, Sirius	106 29 50 ..	sine ..	9·98174
$(\pi'-\pi)$ the diff. of Polar distances	..	co-sec.	0·01266
L = the latitude = 51° 28′ 39″	..	sec. ..	0·20564
	$\overset{s}{0},131$	=	9·11605

Multiply by 15

The azimuthal deviation in arc, west of south .... } = 1,965 ascensions of the stars are to each other the better, as this prevents the possibility of any error arising from a change in the rate of the time-keeper affecting the observations. And as the apparent places of one hundred principal stars are now given in the Nautical Almanac for every tenth day, it will be better to select a pair from thence, which will save the trouble of computing their apparent right ascensions; and, as many suitable pairs are contained therein, it will seldom happen, but that the passage of some of them will occur at a convenient time for observation.

The times of the transits of the two stars being observed (without regard to the *error* of the time-keeper), the deviation of the instrument from the plane of the meridian may be thus determined: Take the difference between the observed passages of the two stars, and also the difference of their computed right ascensions (calling the differences + when the lower star precedes the higher, and *vice versâ); and if these differences be exactly equal, the instrument will be correctly in the plane of the meridian; if they are not equal, their difference, that is to say, the difference of the observed times of transit, ***minus*** the difference of the computed right ascensions, will point out a deviation from that plane, to the eastward of the south when it is +; and west when it is —. As an example, let us take the following:

	Observed Time.		Apparent A.R.
	H. M. S.		H. M. S.
Higher star	5 46 51,91	...	5 46 53,50
Lower „	6 37 25,66	...	6 37 33,66
Difference........... =	— 50 33,75	...	— 50 40,16
Subtract diff. of A.R. =	— 50 40,16		
	+ 6,41		

+ 6,41 = the difference c time ***minus*** the difference of right ascension, which being - shows that the instrument deviates to the eastward of the sou point of the horizon. It is evident that a high star will be le affected by deviation, than one in any other situation, and th a star between the pole and zenith will be *differently* affec from a star south of the zenith, it being observed sooner tha ought when the latter is observed later, and *vice versâ.*

The deviation in azimuth may now be computed from the

						(Brought forward)
Diff. of Intervals .	=	1,87			log.	0·27184
		°	′	″		
π the P. D. of Cephei .	=	2	43	50	sine .	8·67796
π′ „ δ Urs. Min. .	=	3	25	4	sine .	8·77536
Latitude . . .	=	51	28	39	secant	0·20564
(π + π′) sum of the Polar distances .	=	6	8	54	co-sec.	0·97020
				0̊,080	=	8·90100
Multiply by . . .				15		
Deviation from the meridian in space	=			1,200		

In determining the direction of the above deviation, we must observe according to our precepts, that the upper star precedes, and the observed interval is greater than the tabulated interval, therefore the deviation is to the east of north.

This method may now be practised very conveniently, as the apparent places of δ Ursæ Minoris and Cephei 51 *Hev.* are given in the Nautical Almanac. In like manner, Polaris may be combined, though less advantageously, with the stars of the Great Bear.

Again, Polaris, or any close circumpolar star, the place of which is accurately known, may be combined with any star dis-ant from the pole. The simplest mode of considering this is, hat the star which is distant from the pole, gives the *time* or rror of the time-keeper; and again, if Polaris gives the same rror, that the instrument must be in the meridian,* the forula for computation is the same as in the next following ethod, commonly called that of high and low stars, but is uch more accurate.

The last method we shall speak of for correcting the position the instrument, is by observing the transit of any two stars ffering from each other considerably in declination, (at least °) and but little in right ascension. The nearer the right

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Persons desirous of avoiding computation, and who do not want the greatest ible accuracy, may proceed conveniently thus: Get the error of the timeer from stars as near the zenith as may be, levelling with the utmost care e each observation, and reversing the instrument once during the series. By g a mean of the whole, an excellent error of the time-keeper will ected by errors of deviation or collimation, and acting contrary ways upon the time of transit of each star respectively, and hence affecting the interval by their sum, or by $\frac{\sin. \lambda \sin. (\pi + \pi')}{\sin. \pi \sin. \pi'}$. Hence the factor for instrumental deviation $= \frac{\sin. \pi \sin. \pi'}{\sin. \lambda \sin. (\pi + \pi')} \times$ the difference between the observed and computed intervals. When $\pi = \pi'$, or the same star is observed at the upper and lower culmination, this factor becomes $\frac{\tan. \pi}{2 \sin. \lambda} \times$ the difference.

Practical Rule. To the log. of the difference in seconds between the tabulated and observed interval, add the log. sines of the polar distances of the two stars, the log. secant of the latitude, and the log. co-secant of the sum of the two polar distances, reject 40 from the index, and the result will be the log. factor of the deviation, (to be used according to the formula, page 86, in correcting the transits of all stars observed the same night.) And, as before observed, when it is intended to correct the position of the instrument, this quantity, multiplied by 15, will give the deviation from the meridian in space to the east or west of the north.

In determining the *direction* of the deviation, it must be recollected, that when the deviation is to the east, the star above pole passes too early, and that below pole too late, and therefore, if the upper star precedes, the interval is increased, but if the lower precedes, then *vice versâ.* When the deviation is to the west, the star above pole passes too late; while the star below pole passes too early. Hence, if the former precedes, the interval is diminished, and *vice versâ.*

EXAMPLE.

At page 79 we have inserted an extract from the Greenwich Observations for 1834, page 10: we shall take for an example the stars Cephei 51 *Hev.* and δ Urs. Min. S. P.

March 18th, 1834.

		Observation.		Naut. Alm.
		H. M. S.		H. M. S.
Cephei 51 *Hev.* . . .	=	6 20 59,00	.	6 20 19,61
δ Urs. Min. S. P. . .	=	6 26 32,50	.	6 25 51,24
Interval observed	=	5 33,50		5 31,63

from the index, will be the log. factor of deviation, which may be converted into arc by multiplying it by 15.

The correction of this error may be effected by turning the screw, *a*, if the angular value of one revolution be known, unless the instrument possesses an azimuth circle, by which the telescope may be set exactly that quantity from its present position.

But if the quantity of motion to be given to the adjusting-screw, *a*, is not a matter of certainty, the observer, after ascertaining the difference of the intervals, must make the adjustment which he considers sufficient, and again proceed to verify it by observation, until, by continued approximation, he succeeds in fixing his instrument correctly in the meridian.

The above method of determining the instrumental deviation, is wholly independent of the tabulated place of the circumpolar star, but it assumes some knowledge of the rate of the time-keeper, and the *perfect stability* of the instrument for twelve hours; a condition which is rarely to be obtained, except in a regular observatory. The method is still further limited in practice, by the uncertainties of the weather, and the want of stars sufficiently bright to be observed in the daytime, (Polaris being the only star in the northern hemisphere fit for the purpose, and there is no similar star in the southern.) There are, however, two methods almost as good as the preceding, which depend on the *tabulated* places of the stars only. These will now be explained.

Take two *well-known* circumpolar stars, the nearer the pole the better, differing about twelve hours in right ascension, and observe one above and the other below the pole. Now it is evident, that any deviation of the instrument from the meridian will produce *contrary* effects upon the observed times of transit, exactly as in the upper and lower culmination of the same star. Hence, the time which elapses between the two observations will differ from the time which should elapse according to the catalogue, by the *sum* of the effects of the deviation upon the two stars. Compute what effect a deviation of 15″ will produce on the interval, then the difference between the observed interval and computed interval, divided by the quantity thus computed, will be the factor of deviation to be used for correcting transits observed the same night; or, if the deviation itself be required for altering the position of the instrument, multiply this factor by 15, the result will be the deviation to the east or west of the north in seconds of space.

The effect produced on the interval by a deviation of 15″, is to be computed as follows: let π be the polar distance of the

The axis on which the telescope turns must next be set horizontal: to do this, apply the level to the pivots, bring the air-bubble to the centre of the glass-tube, by turning the foot-screw, *b*, which raises or lowers that end of the axis, and consequently the level resting upon it; then reverse the level by turning it end for end, and if the air-bubble still remains central, the axis will be horizontal, but if not, half the deviation must be corrected by the foot-screw, *b*, and the other half by turning the small screw, *i*, at one end of the level, which raises or lowers the glass-tube (containing the air-bubble) with respect to its supports, which rest upon the pivots. This, like most other adjustments, frequently requires several repetitions before it is accomplished, on account of the difficulty of estimating exactly half the error.

Having set the axis on which the telescope turns, parallel to the horizon, and proved the correct position of the central wire or line of collimation, making it describe a great circle perpendicular to that axis, it remains finally to make it move in that vertical circle which is the meridian.

We have supposed the instrument to be nearly in the meridian, the next step is to determine the amount of its deviation, and then by successive approximations to bring it exactly into that plane: one of the methods of accomplishing this, is to observe the time of both the upper and lower transits of Polaris, or any other close circumpolar star, and as the middle wire of the instrument, when exactly in the meridian, bisects the circle which the star apparently describes, round the polar point, in 24 sidereal hours, the time elapsed, during its traversing either the eastern or western semicircle, will be equal to 12 sidereal hours; but should the interval be greater or less, it is clear that the instrument deviates from the meridian. If the eastern interval is greater than the western, the plane in which the instrument moves from the zenith to the north of the horizon, is westward of the true meridian, and *vice versâ*, if the western interval is greatest. Having the difference of the interval from 12 hours, the quantity of deviation measured on the horizon may be computed by the following formula, the latitude of the place, and the polar distance of the star, being both supposed to be known, at least approximately.

$$\text{Deviation} = \log.\frac{\Delta}{2} + \log.\ \sec.\ L + \log.\ \tan.\ \pi - 20:$$

in which expression $\Delta =$ the difference of the intervals from 12^h (reduced to seconds)

$\pi =$ the polar distance of the star

$L =$ the latitude of the place.

This formula, in words, gives the following practical rule:

and the adjustment will be accomplished; but, as half the deviation may not be correctly estimated in moving the wires, it becomes necessary to verify the adjustment by moving the telescope the other half, which is done by turning the screw *a*; this gives the small azimuthal motion to the Y before spoken of, and consequently to the pivot of the axis which it carries. Having thus again bisected the object, reverse the axis as before, and if half the error was correctly estimated, the object will be bisected upon the telescope being directed to it; if not quite correct, the operation of reversing and correcting half the error, in the same manner, must be gone through again, until, by successive approximations, the object is found to be bisected in both positions of the axis; the adjustment will then be perfect. The collimation adjustment may likewise be examined from time to time, by observing the transit of Polaris, or any other close circumpolar star, over the first three wires, which gives the intervals in time from the first to the second, and from the first to the third wire; and then reversing the axis, observe the same intervals in a reverse order, as the wires which were the three first, in the former position, will now be the three last: if the intervals in the first observations are exactly the same as the intervals in the second, the collimation adjustment is correct; but should the corresponding intervals differ, such difference points out the existence of an error, which must be removed, as before described, one half by the collimating screws, and the other half by the azimuthal motion of the instrument.

It is desirable that the central, or middle wire (as it is usually termed) should be truly vertical; as we should then have the power of observing the transit of a star on any part of it, as well as the centre. It may be ascertained whether it is so, by elevating and depressing the telescope: when directed to a distant object, if it is bisected by every part of the wire, the wire is vertical; if otherwise, it should be adjusted, by turning the inner tube carrying the wireplate, until the above test of its verticality be obtained, or else care must be taken that the observations are made near the centre only; the other vertical wires are placed by the maker equidistant from each other and parallel to the middle one, therefore, when the middle one is adjusted, the others are so too; he also places the two transverse wires at right angles to the vertical middle wire. These adjustments are always performed by the maker, and but little liable to derangement. When, however, they happen to get out of order, and the observer wishes to correct them, it is done by loosening the screws which hold the eye-end of the telescope in its place, and turning the end round a small quantity by the hand until the error and they are fixed in their position by an arm of brass, *g*, clamped to the supports by a screw at *h*: the whole of this apparatus is movable with the telescope, and when the axis is reversed, can be attached in the same manner to the opposite standard.

Near the eye-end, and in the principal focus of the telescope, is placed the diaphragm, or wire-plate, which in the theodolite or levelling telescope need only carry two cross wires, but in this instrument it has five vertical and two horizontal wires. The centre vertical wire ought to be fixed in the optical axis of the telescope, and perpendicular with respect to the pivots of the axis. It will be evident upon consideration, that these wires are rendered visible in the daytime by the rays of light passing down the telescope to the eye; but at night, except when a very luminous object, as the moon, is observed, they cannot be seen. Their illumination is therefore effected by piercing one of the pivots, and admitting the light of a lamp fixed on the top of one of the standards, as shown at I; which light is directed to the wires by a reflector placed diagonally in the sphere B; the reflector having a large hole in its centre, does not interfere with the rays passing down the telescope from the object, and thus the observer sees distinctly both the wires and the object at the same time: when however the object is very faint, (as a small star,) the light from the lamp would overpower its feeble rays: to remedy this inconvenience, the lamp is so constructed, that by turning a screw at its back, or inclining the opening of the lantern, more or less light may be admitted to the telescope, to suit the circumstances of the case.

The telescope is furnished with a diagonal eye-piece, by which stars near the zenith may be observed without inconvenience.

Of the Adjustments.

Upon setting the instrument up, it should be so placed that the telescope, when turned down to the horizon, should point north and south as near as can possibly be ascertained. This of course can be but approximate, as the correct determination of the meridian can only be obtained by observation, after the other adjustments are completed.

The first adjustment is that of the line of collimation. Direct the telescope to some small, distant, well-defined object, (the more distant the better,) and bisect it with the middle of the

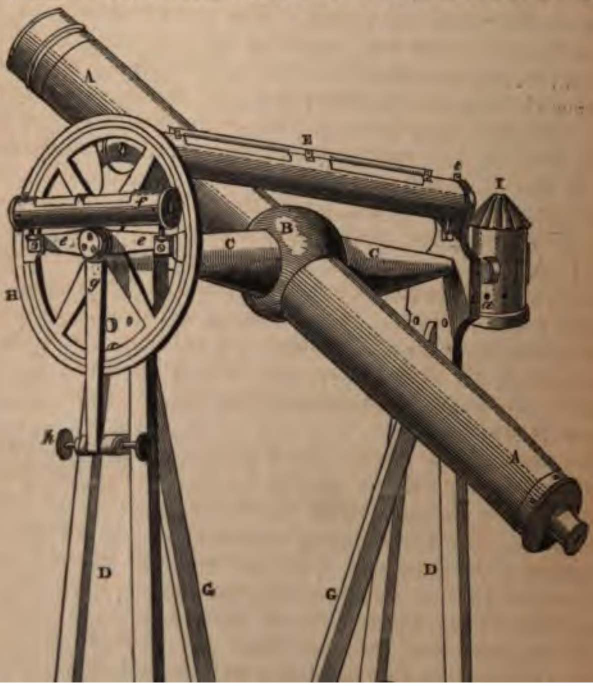
The Transit is a meridional instrument employed, in conjunction with a clock or chronometer, for observing the passage of celestial objects across the meridian, either for obtaining correct time, or determining their difference of right ascension; the latter of which, in the case of the moon and certain stars near her path, that differ but little from her in right ascension, affords the best means of determining the difference of longitude between any two places where corresponding observations may have been made. Such being more especially the use of the *portable* transit instrument, it forms a valuable accession to the apparatus of the scientific traveller, who remaining a short time at any station, is enabled thereby to adjust his time-keepers, both with ease and accuracy, and to obtain the best data for finding his longitude. It also may be employed very successfully in determining the latitude.*

The preceding figure represents this instrument as constructed by Mr. TROUGHTON, when the telescope does not exceed twenty inches, or two feet focal length. The telescope-tube, A A, is in two parts, and connected together by a sphere, B, which also receives the larger ends of two cones, C C, placed at right angles to the direction of the telescope, and forming the horizontal axis. This axis terminates in two cylindrical pivots, which rest in Y's fixed at the upper end of the vertical standards, D D. One of the Y's possesses a small motion in azimuth, communicated by turning the screw, *a*; in these Y's the telescope turns upon its pivots. But, that it may move in a vertical circle, the pivots must be precisely on a level with each other, otherwise the telescope will revolve in a plane oblique (instead of perpendicular) to the horizon. The levelling of the axis, as it is called, is therefore one of the most important adjustments of the instrument, and is effected by the aid of a spirit-level, E, which is made for this purpose to stride across the telescope, and rest on the two pivots.

The standards, D D, are fixed by screws upon a brass circle, F, which rests on three screws, *b c d*, forming the feet of the instrument, by the motion of which the operation of levelling is performed. The two oblique braces, G G, are for the purpose of steadying the supports, it being essential for the telescope to have not only a free but a steady motion. On the extremity of one of the pivots, which extends beyond its Y, is fixed a circle, H, which turns with the axis while the double vernier, *e e*, remains stationary in a horizontal position, and shows the altitude to which the telescope is elevated. The verniers are set horizontal by means of a spirit-level, *f*, which is attached to them, serving. The reading of the second observation will also give double the dip, affected by the same index error as before; and as both readings are on the same side of zero, *one fourth* of their difference will give the true result. Several observations should be taken in each position of the instrument, and the mean taken as the final result.

"In using this instrument at sea for the first time, considerable difficulty arises from the constant change in the plane of the instrument, from the perpendicular position in which it is absolutely necessary that it should be held, in order to obtain a correct observation. What at first appears to be a defect, however, is a real advantage, namely, that whenever it is held in the least degree out of the vertical plane, the two horizons (that seen direct and the reflected one) cross each other, and it is only when the plane is vertical that the horizons can appear parallel."

THE PORTABLE TRANSIT-INSTRUMENT.

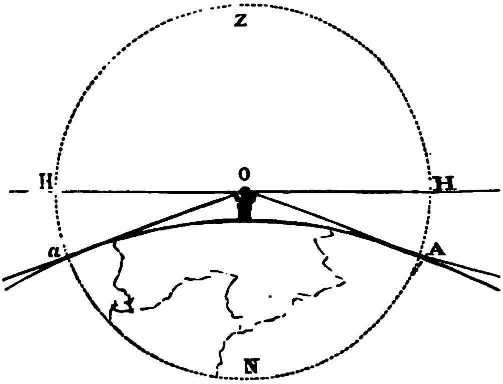


measured by this instrument, for the purpose of obtaining the dip, are A Z *a* and A N *a*, the former of which is 180° + double the dip, and the latter 180° — double the dip, therefore the fourth part of the difference is the measure of the dip. But as the instrument is constructed, only double the dip affected by index error is read from it, and the index error is made so great that the readings are both on the same side of zero, therefore the fourth part of the difference of the readings is the dip angle.

In observing, the face of the instrument must be held in a vertical plane, and lengthwise, in a line with the opposite parts of the horizon whose dip is required; the eye-tube, G F, (page 65) will then be horizontal, and the observer will be looking at right angles to those points of the horizon which he wishes to observe. Suppose the instrument to be held as represented in our engraving, with the index uppermost, the observer will be looking in the direction, G F, when by giving motion to the index B, its glass C will receive *a ray* from the visible horizon on the left hand, and reflect it to the silvered part of the horizon-glass D, and from thence to the telescope; at the same time the whole instrument being moved vertically round the hand as a centre, *a ray* from the opposite part of the horizon to the right hand will pass through the plain or upper part of the horizon-glass, and both rays moving together will pass down the telescope E to F, where by the diagonal mirror they will be reflected, at right angles, to the eye of the observer at G. The index must now be clamped, and by giving motion to the tangent-screw, the two images of the horizon must be made exactly to coincide with each other, and appear as one. To determine when the coincidence is perfect, a slight motion of the instrument will cause the two images to cross each other, by which a judgment may be formed of the accuracy of the observation. This being satisfactorily done, the angle may now be read off, which is the measure of H O A + H O *a*, or double the dip of the horizon, subject to the index error of the instrument. This must be considered but half an observation, and to obtain the correct result, a second observation must be taken with the instrument held in an inverted position, the index being now undermost. This is done by releasing the clamp-screw, J, and turning the handle half round, observe in the same manner as before: but when the brightness of the two opposite parts of the horizon differ considerably, the observer, to avoid the necessity of altering the shades of the two images, (regulated by the up-and-down motion two images of the horizon can thus be made to appear of the shades most favourable for observation. G represents the eyepiece fixed at right angles to the telescope, and a diagonal mirror is placed in the telescope at F, to change the direction of the rays of light, from E F, to F G, in which the observer looks.

The handle, I, turns upon a centre, and is held firmly in any position by tightening the clamp-screw, J. In use it is fixed perpendicular to the length of the instrument, and when wanted it can be turned half round, and fixed in a similar position on the other side, a position in which it is required to be when the instrument is reversed for the second observation; it is turned under and parallel to the instrument when packed in its case.

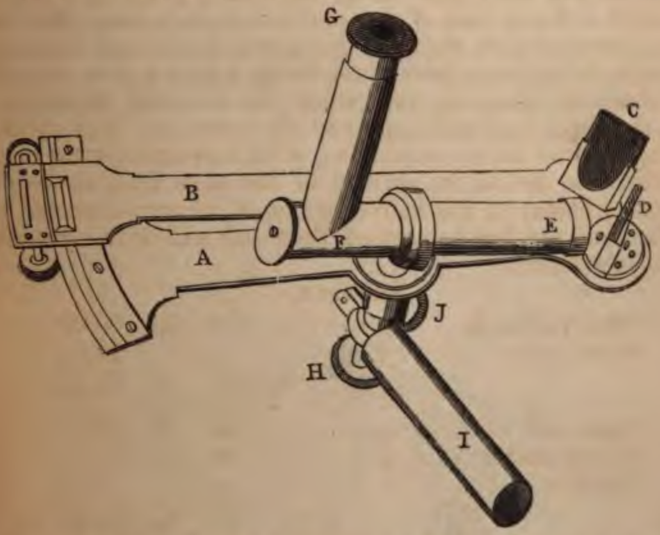
The dip of the horizon, which varies with the height of the observer above the surface of the earth, may always be computed when the height is known; but as a correction of altitudes observed from the horizon of the sea, it is combined with the effects of refraction upon the apparent place of the horizon, which appears elevated above its true place; and as the effects of refraction are extremely variable, the dip obtained by computation is necessarily very uncertain. Tables containing the dip for various altitudes, allowing for the mean effect of refraction, are to be found in all collections of nautical tables. But these tabular dips are at times found to differ so considerably from the truth, especially in tropical climates, that some experienced navigators have lately been induced to measure the actual dip by means of the sector, when any important determination has depended on the observation of altitudes.



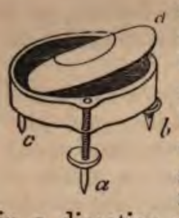
In the above diagram, A *a* represents a portion of the earth's surface, and O the place of an observer; H O H will be his true horizon O A and O *a* his visible horizon; these

THE DIP-SECTOR.

When the late Professor VINCE was engaged in making observations upon extraordinary refraction at Ramsgate, Mr. TROUGHTON contrived and constructed for his use an instrument which he called a Refraction-Sector. About five years afterwards, when preparations were making for the first of the late North Polar Expeditions, Mr. TROUGHTON was applied to by the late Dr. WOOLLASTON, to make him an instrument on the principle of the back observation with the quadrant, to send with the expedition, to measure the dip of the horizon; but upon Mr. TROUGHTON's producing his Refraction-Sector, which was as well adapted to Dr. WOOLLASTON's purpose as that for which it was devised, the Doctor immediately ordered one to be made for him, and named it a Dip-Sector; proposing at the same time an improvement in the construction of the handle, which, on his suggestion, was made to turn on a centre, to be placed in any position, for convenience in use, or packing in its case; that made for Mr. VINCE having two fixed handles, at right angles to the face of the instrument.



The preceding figure represents this instrument: A is the ector, B the index, with its clamp and tangent-screw, exactly imilar to that of the sextant: the index-glass, C, and the horion-glass, D, are fixed at right angles to the plane of the instru-



circular plate of black glass about two inches diameter, mounted on a brass stand, half an inch deep, with three foot-screws, *a b c*, to set the plane horizontal; the horizontality being determined thus by the aid of a short spirit-level, *d*, having under the tube a face ground plane on which it lies in contact with the reflecting surface; place the level on the glass in a direction parallel to the line joining two of the three foot-screws, as *a* and *b*, then move one of these screws till the bubble remains in the middle of the tube in both the reversed positions of the level, and the plate will be horizontal in that direction; then place the level at right angles to its former position, and turn the third foot-screw back or forwards till the bubble again settles in the middle of its tube, the former levelling remaining undisturbed, and the plane will then be horizontal. This instrument, from its portability, is extremely convenient for travellers, as when packed in its case it can be carried in the pocket without being any incumbrance.

When an artificial horizon is used, the observer must place himself at such a distance that he may see the reflected object as well as the real one; then having the sextant properly adjusted, the upper or lower limb of the sun's image (supposing that the object) reflected from the index-glass, must be brought into contact with the opposite limb of the image reflected from the artificial horizon, observing that when the inverting telescope is used, the upper limb will appear as the lower, and *vice versâ*;* the angle shown on the instrument, when corrected for the index error, will be double the altitude of the sun's limb above the horizontal plane; to the half of which, if the semidiameter, refraction, and parallax be applied, the result will be the true altitude of the centre.

EXAMPLE.

	°	′	″
Observed angle	122	25	50,00
Index error	—		17,05
	2) 122	25	32,95
App. alt.	61	12	46,47
Semidiameter	+	15	46,91
Parallax	+		4,00
	61	28	37,38
Refraction	—		34,40
True alt. of sun's centre . .	61	28	2,98

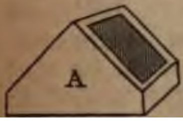
The lid of the box is contrived to screw on the bottom, (as is shown in the plate,) where it makes a convenient handle for holding the instrument.

Since writing the above, we have been shown by Mr. Macneill, an excellent contrivance of his, for taking altitudes or depressions with the box-sextant, which consists of two small spirit-levels fixed at the back of the horizon-glass, at right angles to each other, so that standing before the object, you look perpendicularly down through the plane-sight, and moving the index bring the image of the object to appear with the levels, which must have their air-bubbles in the centre of their tubes. The reading of the instrument will then show the supplement of the zenith distance, and its complement to 90° will be the angle required; elevated if more than 90°, and depressed if less than 90°.

THE ARTIFICIAL HORIZON.

When the altitude of a celestial object is to be taken at sea, the observer has the natural (or sea) horizon, as a line of departure; but on shore, he is obliged to have recourse to an artificial one, to which his observation may be referred: this consists of a reflecting plane parallel to the natural horizon, on which the rays of the sun or other object falling, are reflected back to an eye placed in a proper position to receive them; the angle between the real object and its reflected image, being then measured with the sextant, is double the altitude of the object above the horizontal plane.

Various natural as well as artificial reflecting surfaces have been made by mechanical arrangements, to afford the means of obtaining double angles: such as pouring water, oil, treacle, or other fluid substances into a shallow vessel; and to prevent the wind giving a tremulous motion to its surface, a piece of thin gauze, talc, or plate-glass, whose surfaces are perfectly plane and parallel, may be placed over it, when used for observation. But the most accurate kind of artificial horizon is that in which fluid quicksilver forms the reflecting surface, the containing vessel being placed on a solid basis, and protected from the influence of the wind. The adjoining figure represents an instrument of this kind. The mercury is contained in an oblong wooden trough, placed under the roof A, in which are fixed two plates of glass whose surfaces are plane and parallel to each other. This roof effectually screens the surface of the metal



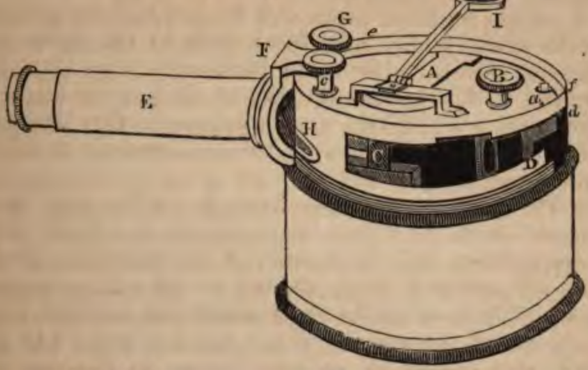
of the limb. The instrument is divided to 30 minutes of a degree, and by the vernier is subdivided to single minutes, one-half of which, or 30 seconds, can be obtained by estimation.

The divided limb is numbered both to the right and left, commencing at 0° to 120°, and backwards from 120° to 180°, and beyond to 230°; the latter row of figures are furthest from the divisions, and belong to the supplementary angles; their zero division of the vernier is at the end, contrary to that of the angles, reading from 0° to 120°.

Beneath the index-glass is fixed a similar one, in such a manner as always to reflect the image of an object to the eye when applied to a hole in the side of the box near the division 120°, at the constant angle of 90°; whence the observer must direct his sight towards the right hand, and at right angles, to the real place of the object. When the index is set to 180°, its glass will also reflect an opposite image to the eye at right angles to the left hand, (the two glasses then being exactly across each other;) consequently an eye looking through the hole near the division 120° will (if the adjustments be perfect) perceive objects 180° apart to coincide, at right angles to a line connecting them. Thus a point can be found in line between two stations: the observer, with the instrument set as above, having placed himself as nearly in the line as he can guess, must apply his eye to the hole near 120°, and looking at right angles to his station line, step backwards or forwards, until he perceives the two distant objects to coincide, when the spot he stands on will be a point in the line joining the objects: to verify this, he should then turn himself half round, and looking in the opposite direction, see if the two objects still coincide, which they will do, if the adjustments of the instrument are correct. If they do not appear in junction, move as before, until you find the spot where they do; then, half way between the two spots so found, will be the true point on the line required.

"The adjustment of this part, as well as the method of observing supplemental angles with it, is performed thus: Choose two objects in the horizon, the further apart the better, but not nearer than 140°; turn your face at right angles to the right-hand object, so as to get sight of its image in the fixed glass; then, by moving the index, bring the image of the other object, seen in the index-glass, exactly to coincide with it on the line of separation of the two glasses: read off the angle, turn yourself half round, and take in like manner the angle which the same objects make the other way. It is evident that the sum of the two angles should be 360°, and also, that if they exceed that quantity, half the excess must be subtracted; and if they fall

THE BOX SEXTANT.



This useful little instrument, which is represented in the above figure, might, perhaps with more propriety, have been classed as a surveying instrument, it being chiefly used in that business. The principle of its construction and adjustments is precisely the same as the sextant before described; a minute description, therefore, would be little more than a recapitulation of what has already been advanced. A is the index, which instead of being moved along the divided limb, *e f*, by the hand, has a motion given to it by a rack and pinion, concealed within the box, and turned by the milled head B, which acts as the tangent-screw does to the index of the large sextant. The glasses (shown at C and D) are within the box, by which they are protected from injury, and their adjustments, when once perfected, kept secure; so much so, that it would require considerable violence to derange them. The horizon-glass, D, alone has a contrivance for adjustment at *a* and *d*, both to set it perpendicular to the plane of the instrument, and to correct or reduce the index error, which, in this instrument, had better be kept correct, as it is not so likely to get out of order as in the large sextant, which, as we have before observed, seldom admits of its index error being rectified. The key, *c*, is formed to fit both squares at *a* and *d*, to make the adjustments, and it is generally tapt into some spare place in the instrument, as at *c*, that it may be always safe and at hand.

It is supplied with a telescope, E, which screws into a shoulder-piece, F, and can be attached to the box by the screw, G: this can be applied or not, at the pleasure of the observer, as there is a contrivance at H to enable him to observe without

"The advantages of this instrument, when compared with the sextant, are chiefly these: the observations for finding the index error are rendered useless, all knowledge of that being put out of the question, by observing both forwards and backwards. By the same means the errors of the dark glasses are also corrected; for, if they increase the angle one way, they must diminish it the other way by the same quantity. This also perfectly corrects the errors of the horizon-glass, and those of the index-glass very nearly. But what is still of more consequence, the error of the centre is perfectly corrected by reading the three branches of the index; while this property combined with that of observing both ways, probably reduces the errors of dividing to one-sixth part of their simple value. Moreover, angles may be measured as far as one hundred and fifty degrees, consequently the sun's double altitude may be observed when his distance from the zenith is not less than fifteen degrees; at which altitude, the head of the observer begins to intercept the rays of light incident on the artificial horizon; and, of course, if a greater angle could be measured, it would be of no use in this respect.

"This instrument, in common with the sextant, requires three adjustments. First, the index-glass perpendicular to the plane of the circle. This being done by the maker, and not liable to alter, has no direct means applied to the purpose; it is known to be right, when, by looking into the index-glass, you see that part of the limb which is next you, reflected in contact with the opposite side of the limb, as one continued arc of a circle: on the contrary, when the arc appears broken, where the reflected and direct parts of the limb meet, it is a proof that it wants to be rectified. The second is, to make the horizon-glass perpendicular. This is performed by a capstan-screw, at the lower end of the frame of that glass; and is known to be right, when, by a sweep of the index, the reflected image of any object will pass exactly over, or cover the image of that object seen directly. The third adjustment is, for making the line of collimation parallel to the plane of the circle. This is performed by two small screws, which also fasten the collar into which the telescope screws to the upright stem on which it is mounted; this is known to be right, when the sun and moon, having a distance of one hundred and thirty degrees, or more, their limbs are brought in contact, just at the outside of that wire which is next to the circle; and then, examining if it be the same, just at the outside of the other wire: its being so is the proof of adjustment.

"Should these hints about the adjustments set any over-handy the same day, because there is not time: all therefore that can be done, is, to observe the altitude one way, and use the index error; but even here, you have a mean of that altitude, and this error, taken on three different sextants. Both at sea and land, where the observer is stationary, the meridian altitude should be observed forwards one day, and backwards the next, and so on alternately from day to day; the mean of latitudes, deduced severally from such observations, will be the true latitude; but in these there should be no application of index error, for that being constant, the result would in some measure be vitiated thereby.

"When both the reflected and direct images require to be darkened, as is the case when the sun's diameter is measured and when his altitude is taken with an artificial horizon, the attached dark glasses ought not to be used: instead of them, those which apply to the eye-end of the telescope will answer much better: the former having their errors magnified by the power of the telescope, will, in proportion to this power, and those errors, be less distinct than the latter.

"In taking distances, when the position does not vary from the vertical above thirty or forty degrees, the handles which are attached to the circle are generally most conveniently used; but in those which incline more to the horizontal, that handle which screws into a cock on one side, and into the crooked handle on the other, will be found more applicable.

"When the crooked handle happens to be in the way of reading one of the branches of the index, it must be removed, for the time, by taking out the finger-screw, which fastens it to the body of the circle.

"If it should happen that two of the readings agree with each other very well, and the third differs from them, the discordant one must not on any account be omitted, but a fair mean must always be taken.

"It should be stated, that when the angle is about thirty degrees, neither the distance of the sun and moon, nor an altitude of the sun, with the sea horizon, can be taken backwards; because the dark glasses at that angle prevent the reflected rays of light from falling on the index-glass; whence it becomes necessary, when the angle to be taken is quite unknown, to observe forwards first, where the whole range is without interruption; whereas in that backwards, you will lose sigh
eflected image about that angle. But

words of the inventor, Mr. Troughton, contained in a paper which he calls

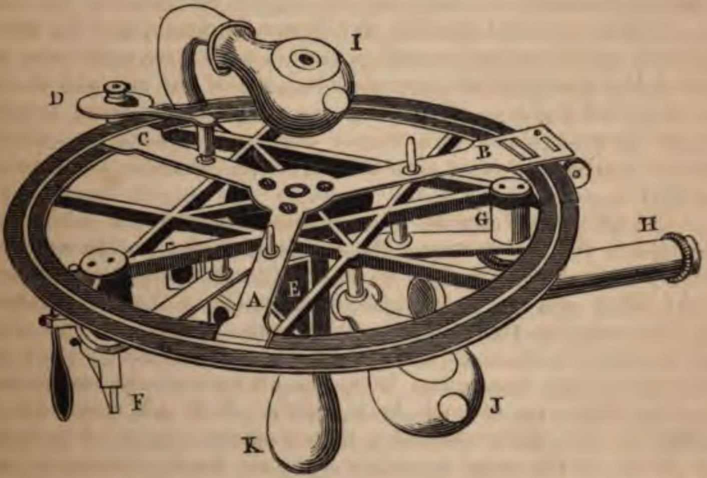
" *Directions for observing with Troughton's Reflecting Circle.*

" Prepare the instrument for observation by screwing the telescope into its place, adjusting the drawer to focus, and the wires parallel to the plane, exactly as you do with a sextant: also set the index forwards to the rough distance of the sun and moon, or moon and star; and holding the circle by the short handle, direct the telescope to the fainter object, and make the contact in the usual way. Now read off the degree, minute, and second, by that branch of the index to which the tangent-screw is attached; also, the minute and second shown by the other two branches; these give the distance taken on three different sextants; but as yet, it is only to be considered as half an observation: what remains to be done, is to complete the whole circle, by measuring that angle on the other three sextants. Therefore set the index backwards nearly to the same distance, and reverse the plane of the instrument, by holding it by the opposite handle, and make the contact as above, and read off as before what is shown on the three several branches of the index. The mean of all six is the true apparent distance, corresponding to the mean of the two times at which the observations were made.

" When the objects are seen very distinctly, so that no doubt whatever remains about the contact in both sights being perfect, the above may safely be relied on as a complete set; but if, from the haziness of the air, too much motion, or any other cause, the observations have been rendered doubtful, it will be advisable to make more: and if, at such times, so many readings should be deemed troublesome, six observations, and six readings may be conducted in the manner following: Take three successive sights forwards, exactly as is done with a sextant; only take care to read them off on different branches of the index: also make three observations backwards, using the same caution: a mean of these will be the distance required. When the number of sights taken forwards and backwards are unequal, a mean between the means of these taken backwards and those taken forwards will be the true angle.

" It need hardly be mentioned, that the shades, or dark glasses, apply like those of a sextant, for making the objects nearly of the same brightness; but it must be insisted on, that the telescope should, on every occasion, be raised or lowered, by its proper screw, for making them perfectly so.

TROUGHTON'S REFLECTING CIRCLE.



The above figure represents this instrument, which in principle and use is the same as the sextant. It has three vernier readings, A B C, moving round the same centre as the index-glass, E, which is upon the opposite face of the instrument. One of the than it can when seen by reflection. If the brighter object is to the left, the sextant must be held with the face downwards.

The enlightened limb of the moon is always to be brought into contact with the sun or star, even though the moon's image is made to pass beyond the sun or star before the desired contact can be obtained.

Perhaps the best method of taking a lunar distance is, not to attempt to make the contact perfect by the tangent-screw, but when the nearest limbs are observed, make the objects overlap each other a little when they are receding, or leave a small space between them when they are approaching, and wait till the contact is perfect, and the reverse, when the furthest limbs are observed.

The altitudes of the two objects should be observed at the same instant as the distance, and the time noted by a chronometer, or watch: this would require several observers; but one person may take them all, by having recourse to the following method: "First, observe the altitude of the sun or star; secondly, the altitude of the moon; then any number of distances; next the altitude of the moon, and lastly the altitude of the sun or star, noting the times of each by a watch. Now add together the distances and times when they were observed, and take the mean of each; and in order to reduce the altitudes to the mean time, making the following proportion: As the difference of times between the observations is to the difference of their altitudes, so is the difference between the time that the first altitude was taken and the mean of the times at which the distances were observed, to a fourth number: which, added to or subtracted from the first altitude, according as it is increasing or decreasing, will give the altitude reduced to the mean time."

The angular distances of terrestrial objects are measured by the sextant in the same manner as those of celestial ones; but if the objects are not in the same horizontal plane, a reflecting instrument will not give their horizontal angular distance. But this may be obtained nearly by measuring their angular distances from an object in or near the horizon, which subtends a great angle with both, and the sum, or the difference of the angles so measured, will be nearly the required horizontal angle.

Of the sextant, it has been said, that it is in itself a portable observatory; and it is doubtless one of the most generally useful instruments that has ever been contrived, being capable of furnishing data to a considerable degree of accuracy for the solution of a numerous class of the most useful astronomical problems;

horizon is employed, the two images of the sun must be brought into contact with each other; but this will be explained when speaking of that instrument. To the angle read off apply the index error, and then add or subtract the sun's semidiameter, as given in the Nautical Almanac, according as the lower or upper limb is observed, to obtain the apparent altitude of the sun's centre. Before we can use this observation for determining the time, the latitude, &c., it must be further corrected for refraction and parallax, to obtain the true altitude, subtracting the former and adding the latter; and when the sea horizon is employed, a quantity must also be subtracted for the dip, which is unnecessary when the altitude is taken by means of an artificial horizon.

Tables for obtaining the above corrections may be found in Mr. Baily's Astronomical Tables, &c., in the Requisite Tables, or in any modern work on navigation.

EXAMPLE.

			°	′	″
Obs. alt. of the sun's lower limb		=	61	13	5
Index error		= —			17
Apparent altitude		=	61	12	48,0
* Sun's semidiameter		= +		15	46,9
„ parallax		= +		0	4,0
Refraction..................	— 34,4″		61	28	38,9
Dip of the horizon, for an elevation of 18 feet...	—4 3,0	= —		4	37,4
True altitude of the sun's centre		=	61	24	1,5

If the observer is ignorant of the precise moment of the object's being on the meridian, he should, by a slow and gradual motion of the tangent-screw, keep the observed limb in contact with the horizon as long as it continues to rise; and immediately on the altitudes appearing to diminish, cease from observing, and the angle then read on the instrument will be the meridian altitude.

After what has been advanced, little need be said about observing lunar distances, whether of the moon and the sun, or the moon and a fixed star or planet, except that the instrument must be held in the plane of the two objects, and it is generally preso as to make his perpendicular diameter appear less than his horizontal one, which is that given in the Nautical Almanac: in this case the sextant must be held horizontally.

To make the Line of Collimation of the Telescope parallel to the Plane of the Sextant.

This is known to be correct, when the sun and moon, having a distance of 90° or more, are brought into contact just at the wire of the telescope which is nearest the plane of the sextant, fixing the index, and altering the position of the instrument to make the objects appear on the other wire; if the contact still remains perfect, the axis of the telescope is in proper adjustment; if not, it must be altered by moving the two screws which fasten, to the up-and-down piece, the collar into which the telescope screws. This adjustment is not very liable to be deranged.

Having now gone through the principle and construction of the sextant, it remains to give some instructions as to the manner of using it.

It is evident that the plane of the instrument must be held in the plane of the two objects, the angular distance of which is required: in a vertical plane, therefore, when altitudes are measured; in a horizontal or oblique plane, when horizontal or oblique angles are to be taken. As this adjustment of the plane of the instrument is rather difficult and troublesome to the beginner, he need not be surprised nor discouraged, although his first attempts may not answer his expectations. The sextant must be held in the right hand, and as slack as is consistent with its safety, for in grasping it too hard the hand is apt to be rendered unsteady.

When the altitude of an object, the sun, for instance, is to be observed, the observer, having the sea horizon before him, must turn down one or more of the dark glasses, or shades, according to the brilliancy of the object; and directing his sight to that part of the horizon immediately beneath the sun, and holding the instrument vertically, he must with the left hand lightly slide the index forward, until the image of the sun, reflected from the index glass, appears in contact with the horizon, seen through the unsilvered part of the horizon glass. Then clamp it firm, and gently turn the tangent-screw, to make the contact of the upper or lower limb of the sun and the horizon perfect, when it will appear a tangent to his circular disc.[*] If an artificial

[*] [illegible]

to the error itself: therefore, in modern instruments, there are seldom any means applied for its correction, it being considered preferable to determine its amount previous to observing, or immediately after, and apply it with its proper sign to each observation. The amount of the index error may be found in the following manner: clamp the index at about 30 minutes to the left of zero, and looking towards the sun, the two images will appear either nearly in contact or overlapping each other; then perfect the contact, by moving the tangent-screw, and call the minutes and seconds denoted by the vernier, the reading on the arc. Next place the index about the same quantity to the right of zero, or on the arc of excess, and make the contact of the two images perfect as before, and call the minutes and seconds on the arc of excess* the reading off the arc; and half the difference of these numbers is the index error; additive when the reading on the arc of excess is greater than that on the limb, and subtractive when the contrary is the case.

EXAMPLE.

Reading on the arc . . .		31′	56″
,, off the arc . . .		31	22
Difference		0	34
Index error . . .	=	— 0	17

In this case the reading on the arc being greater than that on the arc of excess, the index error, =17 seconds, must be subtracted from all observations taken with the instrument, until it be found, by a similar process, that the index error has altered. One observation on each side of zero is seldom considered enough to give the index error with sufficient exactness for particular purposes: it is usual to take several measures each way; "and half the difference of their means will give a result more to be depended on than one deduced from a single observation only on each side of zero." A proof of the correctness of observations for index error is obtained by adding the above numbers together, and taking one-fourth of their sum, which should be equal to the sun's semidiameter, as given in the Nautical Almanac. When the sun's altitude is low, not exceeding 20° or 30°, his horizontal instead of his perpendicular diameter should be measured, (if the observer intends to compare with the Nautical Almanac, otherwise there is no necessity;) because the refraction at such an

Of the Adjustments.

The requisite adjustments are the following: the index and orizon glasses must be perpendicular to the plane of the instruient, and their planes parallel to each other when the index diision of the vernier is at 0° on the arc, and the optical axis of he telescope must be parallel to the plane of the instrument. Ve shall speak separately of each of these adjustments.

To examine the Adjustment of the Index-glass.

Move the index forward to about the middle of the limb; then, olding the instrument horizontally with the divided limb from he observer, and the index-glass to the eye, look obliquely down he glass, so as to see the circular arc, by direct view and by reection, in the glass at the same time; and if they appear as one ontinued arc of a circle, the index-glass is in adjustment. If t requires correcting, the arc will appear broken where the reected and direct parts of the limb meet. This in a well-made nstrument is seldom the case, unless the sextant has been exosed to rough treatment. As the glass is in the first instance et right by the maker, and firmly fixed in its place, its position s not liable to alter, therefore no direct means are supplied for ts adjustment.

To examine the horizon-glass, and set it perpendicular to the Plane of the Sextant.

The position of this glass is known to be right, when by a weep with the index, the reflected image of any object passes xactly over or covers its image as seen directly; and any error s easily rectified by turning the small screw, *i*, at the lower end f the frame of the glass.

To examine the Parallelism of the Planes of the two Glasses, when the Index is set to Zero.

This is easily ascertained; for, after setting the zero on the ndex to zero on the limb, if you direct your view to some object, he sun for instance, you will see that the two images (one seen y direct vision through the unsilvered part of the horizon-glass, nd the other reflected from the silvered part) coincide or appear s one. if the glasses are correctly parallel to each other: but if the plane of the instrument, and in such a position that its plane shall be parallel to the plane of the index-glass, F, when the vernier is set to 0° (or zero) on the limb, B C. A deviation from this position constitutes the index error before spoken of.

The telescope is carried by a ring, L, attached to a stem, *e*, called the up-and-down piece, which can be raised or lowered by turning the milled screw, M: its use is to place the telescope so that the field of view may be bisected by the line on the horizon-glass that separates the silvered from the unsilvered part. This is important, as it renders the object seen by reflection, and that by direct vision equally bright;* two telescopes and a plain tube, all adapted to the ring, L, are packed with the sextant, one showing the objects erect, and the other inverting them; the last has a greater magnifying power, showing the contact of the images much better. The adjustment for distinct vision is obtained by sliding the tube at the eye-end of the telescope in the inside of the other; this also is the means of adapting the focus to suit different eyes. In the inverting telescope are placed two wires, parallel to each other, and in the middle of the space between them the observations are to be made, the wires being first brought parallel to the plane of the sextant, which may be judged of with sufficient exactness by the eye. When observing with this telescope, it must be borne in mind, that the instrument must be moved in a contrary direction to that which the object appears to take, in order to keep it in the field of view.

Four dark glasses, of different depths of shade and colour, are placed at K, between the index and horizon glasses; also three more at N, any one or more of which can be turned down to moderate the intensity of the light, before reaching the eye, when a very luminous object (as the sun) is observed. The same purpose is effected by fixing a dark glass to the eye-end of the telescope: one or more dark glasses for this purpose generally accompany the instrument. They, however, are chiefly used when the sun's altitude is observed with an artificial horizon, or for ascertaining the index error, as employing the shades attached to the instrument for such purposes, would involve in the result, any error which they might possess. The handle, which is shown at O, is fixed at the back of the instrument. The hole in the middle is for fixing it to a stand, which is useful when an observer desirous of great steadiness.

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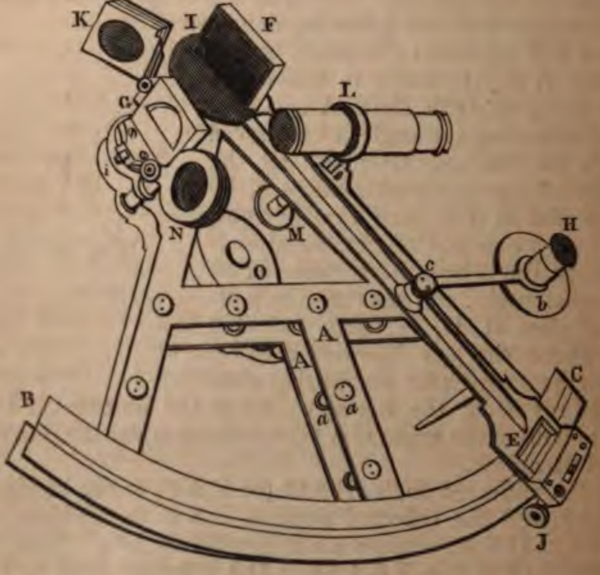
* This is not the case when one object is much brighter than the other, as the and moon; in taking the distance between which, the screw, M, should be ed more than above stated, until they are both nearly of the same

he annexed figure represents a sextant of TROUGHTON's con-
ction, having a double frame, A A, connected by pillars, *a a*,
, thus uniting strength with lightness. The arc, B C, is ge-
lly graduated to 10′ of a degree, commencing near the end,
nd it is numbered towards B. The divisions are also con-
ed on the other side of zero, towards C, forming what is
ed the arc of excess, which is useful in determining the index
r of the instrument, as will be explained hereafter. The
b is subdivided by the vernier, E, into 10″, the half of which
5″) can be easily estimated: this small quantity is easily dis-
uishable by the aid of microscope, H, and its reflector, *b*,
ch are connected by an arm with the index, I E, at the point *c*,
nd which it turns as a centre, affording the means of examin-
the whole vernier, the connecting arm being long enough to
w the microscope to pass over the whole length of it.



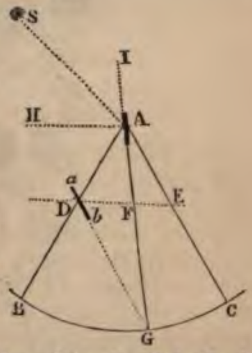
o the index is attached a clamp to fasten it to the limb, and
ngent screw, J, (in the plate, the clamp is concealed from
,) by which the index may be moved any small quantity,
it is clamped, to render the contact of the objects observed
e perfect than can be done by moving it with the hand alone.
upper end, I, terminates in a circle, across which is fixed the
red index-glass, F, over the centre of motion, and perpen

ASTRONOMICAL INSTRUMENTS.

THE SEXTANT.

It was our intention, before describing tbe Sextant, to devote some space to an account of HADLEY's Quadrant; but as the construction of both instruments is essentially the same, we shall confine ourselves to a description of the sextant and its uses only, as comprehending the other instrument, and performing with greater correctness all the operations to which the quadrant can be applied. The principle of its construction may be understood from the following demonstration.

Let A B C represent a sextant, having an index, A G, (to which is attached a mirror at A,) movable about A as a centre, and denoting the angle it has moved through, on the arc, B C; also let the half-silvered (or horizon) glass, *a b*, be fixed parallel to A C; now a ray of light, S, A, from a celestial object, S, impinging against the mirror, A, is reflected off at an equal angle, and striking the half-silvered glass at D, is again reflected to E, where the eye likewise receives through the transparent part of that glass a direct ray from the horizon. Then the altitude, S A H, is equal to double the angle C A G, measured upon the limb, B C, of the instrument.



For the reflected angle, B A G (or D A F) = the incident angle, S A I, and the reflected angle, *b* D E = the incident *a* D A = D A E = D E A, because *a b* is parallel to A C. Now, H A I = D F A = (F A E + F E A,) and D A E being equal to D E A, it follows that H A I = (D A E + F A E.) From H A I and (D A E + F A E) take the equal angles, S A I and D A F, and there remains S A H = 2 F A E, or 2 G A C; or, in other words, the angle of elevation, S A H, is equal to double the angle of inclination of the two mirrors, D G A, being equal to G A C.

Hence the arc on the limb, B C, although only the sixth part

EXAMPLE.

The following observations were made in the transit-room of the Royal Observatory, and at the base of the statue of George II. in Greenwich Hospital, latitude 51° 28′ to determine the difference of altitude.

	Upper Station.	Lower Station.
Detached thermometer . . .	71° 5 . . .	71° 5
Attached ditto . . .	70 0 . . .	70 0
Barometer, mean of 5 obs. .	29 870 inches	30 014 in.

A = 4·81719
B = ... 0·00000
C = 9·99976
log. of bar. upper station, 1·47524

1·47524
log. of bar. lower station, 1·47732

7·31806 log. . . . . . . R = 0·00208

Sum 2·13501 log. of 136·46 feet, the diff. of altitude.

The difference of altitude, as obtained by levelling with the spirit-level, (Phil. Trans. 1831, Part I.) = 135·57 feet, differing only 0·89 feet from that obtained above. The observations should be made simultaneously at both stations, but to do this, two observers and two barometers are required. When there is only one observer, he should, after making his first observations, lose no time in hastening to his second station, to make his observations there ; which, if done quickly, and the atmosphere is undergoing no change at the time, will answer nearly as well as if simultaneous observations were made by a barometer at each station.

from the instrument, is employed at the same time, to show the temperature of the surrounding air.

The barometrical method of determining differences of level, is founded upon the principle that the strata of air decrease in density, in a geometrical proportion, when the elevations above the surface of the earth increase in an arithmetical one. Therefore, from the known relation between the densities and the elevations, we can discover the elevations by observations made on the densities by means of the barometer.

Observe at the same time the height of the mercurial columns at both the stations, whose difference of elevation is required, and also the temperature of the instrument by the thermometer attached thereto; and that of the surrounding air by another, called the detached thermometer.*

The computations for deducing the difference of height from these observations, is rendered very easy by means of Table II. which is computed by the formula given by Mr. Baily, in his volume of Astronomical Tables and Formulæ, and is similar to Table XXXVI. in the same volume, but more extended.

The following is the method of using the Table.

Find in the column headed "S" the sum of the degrees read on the detached thermometers at the two stations, and take out the corresponding number from the adjoining column, headed "A"; next in the column D, find the difference of the degrees read on the attached thermometers, and take out the opposite number in the column B; lastly, from the column C, take out the number opposite the latitude of the place of observation, found in the column L; then,

When the upper thermometer reads less than the lower one.

To the number called B, add the log. of the height of the barometer at the upper station, and subtract their sum from the log. of the height of the barometer at the lower station, and call the remainder R; then take out the log of R and add it to the numbers A and C, and the sum, rejecting the tens from the index, will be the log. of the difference of the altitudes of the two stations in feet.

When the upper thermometer reads more than the lower one.

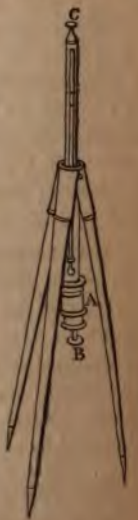
To the log. of the height of the barometer at the lower station add the number called B, and from their sum subtract the log. of the height of the barometer at the upper station, and call the remainder R; then take out the log of R, and add it to the

the height 38 feet, 760 divided by 38 gives 20; showing the rate of inclination to be 1 in 20.

The rate of inclination may likewise be found by observing the angle of elevation or depression; and Table X., at the end of the volume, shows the corresponding inclination.

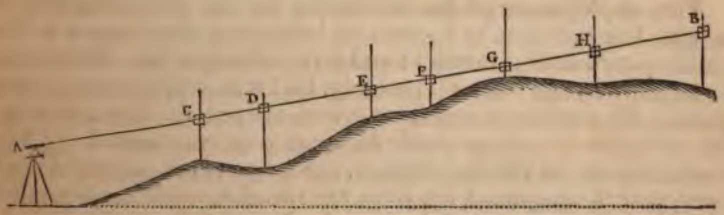
LEVELLING WITH THE MOUNTAIN BAROMETER.

The employment of the barometer for the determination of heights has caused it to become an interesting instrument to the philosopher and the traveller; and many attempts have been made to improve it, and render it portable, that it may be conveyed from place to place, without much inconvenience or risk. The following figure represents the portable barometer as constructed by Mr. TROUGHTON. In the brass box, A, which covers the cistern of mercury, near the bottom of the tube, are two slits, made horizontally, precisely similar and opposite to each other, the plane of the upper edges of which represent the beginning of the scale of inches, or zero of the barometer. The screw B, at the bottom, performs a double office; first, it is the means of adjusting the surface of the mercury in the glass cistern to zero, by just shutting out the light from passing between it and the upper edges of the above-named slits; and, secondly, by screwing it up, it forces the quicksilver upwards, and by filling every part of the tube, renders the instrument portable.



The divided scale on the upper part, is subdivided, by the help of a vernier, to the five hundredth part of an inch. The screw C, at the top, moves a sliding piece, on which the vernier scale is divided, the zero of which is at the lower end of the piece. In taking the height of the mercury, this sliding piece is brought down and set nearly by the hand, and the contact of the zero of the vernier with the top of the mercurial column is then perfected by the screw C, which moves the vernier the small quantity that may be required just to exclude the light from passing between the lower edges of the sliding piece, and the spherical surface of the mercury.

The barometer is attached to the stand by a ring, in which it turns round with a smooth and steady motion, for the purpose of placing it in the best light for reading off, &c.; and the tripod difference of level between the extreme, or any two stations, may be found by simply taking the difference of the sums of the intervening elevations and depressions.



A theodolite of larger dimensions than those we have described at page 15, &c., and capable of measuring vertical angles with great accuracy, may be advantageously applied to take the levels of a continually rising line of section; thus, suppose the theodolite set up at A, and the telescope elevated so that the line of sight, A B, may coincide with the vane on a staff exactly at the same height from the ground as the instrument; suppose the staff placed at B, the angle of elevation being carefully noted, the instrument must remain perfectly steady whilst the observer is watching an assistant passing along the line with a staff, which he successively holds up at every change of inclination, as at C D E, &c., the staff-man raising or lowering the vane until the observer perceives the cross wires of the telescope (or line of sight, A B,) to coincide with that on the vane; the height on the staff is then read off and noted, which gives the depression of that spot of ground below the line A B, which being done along the whole distance, and a mark made on the ground at each spot, that the distances may likewise be measured, unless determined by a micrometer, as explained at page 29, the undulations of the surface below the line A B is determined; and the inclination of the line of sight being likewise obtained with the theodolite, the requisite data for drawing the section is obtained. This method has been successfully practised by John Macneill, Esq., the engineer of the London and Holyhead roads, with an instrument purposely constructed by Messrs. Troughton and Simms, which is not exactly a theodolite, but rather a large spirit-level, capable of measuring vertical angles with great precision, and has a delicate wire micrometer attached to the eye-end of the telescope, by which the distances of the staff from the instrument are accurately determined.

After having obtained the difference of level from station to

		Ft.	In.
Sum of forward stations corrected for curvature	=	69	1,36
Sum of back stations	=	28	9,53
Difference of level, between extreme stations	=	40	3,83

		Feet.
Sum of distances from the instrument to the back stations		7487
Sum of distance to forward stations		11470
Whole distance levelled	=	18957

In this example, the difference of level being taken in feet and inches, the corrections from Table I. have been multiplied by 12, in order to render them decimals of inches, they being, as contained in the Table, decimals of feet; consequently, if the levels had been taken in feet and decimals of feet, the corrections would have been applied at once as taken from the Table.

LEVELLING WITH THE THEODOLITE.

The use of the theodolite as a levelling instrument consists in taking a series of angles of elevation and depression along the line, the section of which is required. This must be done at every point where the inclination of the line changes, and the distance measured between the instrument and the station-staff. This distance, it will be evident, is the hypothenuse of a right-angled triangle; the perpendicular of which is the difference of level. To insure accuracy, the angles should be observed both forwards and backwards, by making the instrument and staff change places; and a mean of the two measures should be taken as the correct angle. The instrument should be set up (as nearly as possible) at a constant height from the ground, and the staff used for the observations should have a fixed vane, or conspicuous mark on it, at exactly the same height from the ground as the centre of the telescope, which mark must be bisected by the cross-wires in observing. Great care should be taken that the adjustments of the instrument are correct, more particularly that of the line of collimation, and the level attached to the telescope.

With the measured distance, and the observed angle, the difference of level may be computed, by adding to the logarithm of the measured distance, the log. sine of the vertical angle, and their sum, rejecting 10 from the index, will be the log. of the known hereafter. Their use is chiefly for future reference, in the event of its being necessary, either to check the levels by repetition, to change the direction of the line of levels from any point, or to take up and continue the levels at the commencement of a day's work, a bench-mark having been left at the close of the day preceding: in the latter case, it is more common to leave a peg driven into the ground to renew the work at. When the staff is placed on a bench-mark, the bed of a river, or on any object out of the direct line of levels, the same method of entry and computation must be adopted, as shown in our example where the bed of the river was taken, no bearing or distance was noticed, but the name of the object entered instead; the computation is precisely the same as before, but when the next forward station was about to be observed, the reading taken to the bed of the river, viz., 10·50, was entered in the column as a back observation, against which, the forward reading with its bearing and distance was placed; but as both observations were taken from the same spot, they are considered as belonging to the sixth station, as also would any number of intermediate levels; the seventh station being that which has the next back observation taken in the actual line of levelling, this distinction is sufficiently conspicuous to prevent the draftsman plotting the wrong levels in the section, as common bench-marks are not usually noticed in it. In making a section, it is of importance to take the level of all considerable hollows in the ground, the bed of any river, as near the centre as can be obtained, and also of public and private roads.

It is not common to apply the correction for the curvature of the earth, except where extreme accuracy is required; but by way of illustrating the use of Table I. we have annexed the following example.

No. of back Station.	Back Station.	Dist. of Instrument from Station.	Correct. for Curvat.	Height of Instrument.	Forward Station.	Dist. of Instrument from Station.	Correct. for Curvat.	Remarks.
	Ft. In. Dec.	Feet.	In. Dec.	Ft. In.	Ft. In. D.	Feet.	In. Dec.	
1	3 1,7	1200	0,413	4 4	11 2,6	800	0,184	
2	6 1,6	480	0,066	4 6	8 1,7	960	0,264	
3	1 7,3	1479	0,629	4 3	6 2,4	1220	0,427	
4	2 4,8	984	0,276	4 7	10 8,3	2160	1,339	
5	4 8,3	764	0,166	4 0	9 3,8	1190	0,406	
6	0 10,2	280	0,022	4 1	11 7,3	340	0,033	
7	7 8,7	1640	0,772	4 5	8 2,1	3100	2,759	
8	2 5,4	660	0,125	4 4	4 3,4	1700	0,829	
Sum	29 0,0	7487	2,469		69 7,6	11470	6,241	
Cor.	2.47				6.24			

The contents of each column may be known by the various headings. At the commencement of the operation, the first back station is assumed to be 100 feet above the horizontal line, which is done to avoid the introduction of plus and minus signs in the calculation: this being placed at the top of the column to contain the reduced levels, the reading of the forward station must be subtracted from it, and to the remainder must be added the reading of the back station, which completes the first level, the result being the height of the forward station above the assumed horizontal line; thus, in the first level, from 100 subtract 14·97, and it leaves 85·03, to which add 2·15, and the result is 87·18, which is the height of the second station, assuming the first to have been 100 feet above the horizontal line: the operation for each of the succeeding levels is precisely similar. The difference of level between any two points in the section may be obtained by simply taking the difference of the heights: thus to obtain the difference between the first and fourth level, from 87·18 subtract 44·48=42·70 the difference required, and the difference between 100 feet (the assumed height of the starting point) and any other level in the book will be the difference of altitude between those points: thus, in our example, to find how much the bed of the river is below the point of commencement, subtract 29·28 from 100, and the remainder, 70·72, is the quantity required.

As a check upon the accuracy of the computation, it is necessary to add up the contents of the two columns on each page containing the back and fore observations, and subtracting the less from the greater, the difference shows the whole amount of the rise or fall of the ground (as in the example given at page 40); and if both computations have been correctly made, it will be identical with the difference as shown in the column of reduced levels: thus in our example, page 41, the sum of the back sights is 30·81, and the sum of the fore sights is 86·87; their difference is 56·06, which, taken from 100, (because the first station was assumed to be that height) leaves 43·94, the same as given by the reduced levels.

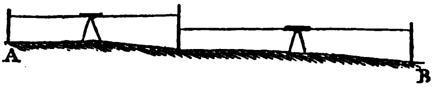
There is also another mode of reducing levels, by having two columns, one headed "rise," and the other "fall," in one of which the difference between the back and fore sight must be entered, according as the ground is rising or falling; and then, by the continual adding or subtracting of these quantities, (in a separate column,) the reduced levels are obtained, without assuming the first station to be 100, or any other number of feet high.

for it not unfrequently happens, that sufficiently intelligent persons cannot be procured in obscure country places to hold and read off the staff. Besides the greater facility and less liability to error, the observer, with scarcely any loss of time, can make his calculations as he proceeds, so that following each level, the book contains the absolute difference of level of any station, above or below a horizontal line drawn through a point assumed as the standard level or point of comparison. This saves a deal of after-trouble in the office, as every requisite is prepared in the field for laying down the section.

The following example shows the form of a levelling book; in which the first staff is called the back station, and the second staff the forward station; when the first forward station will become the second back station, the second forward, the third back, &c.

No. of Station.	Back Station.			Forward Station.			Reduced Levels.
	Bearing.	Distance.	Staff.	Staff.	Distance.	Bearing.	
	°		Ft.	Ft.		°	
1	300·20	140	2·15	14·97	358	120·10	100·00 14·97 85·03 2·15
2	300·40	89	0 50	15·14	420	120·12	87·18 15·14 72·04 0·50
3	300·15	106	0·54	14·12	275	120·0	72·54 14·12 58·42 0·54
4	300·10	109	0·83	15·31	337	120·0	58·96 15·31 43·65 0·83
5	300·0	128	1·49	12·15	609	120·0	44·48 12·15 32·33 1·49
6	300·0	592	5·96	10·50	Bottom	of River	33·82 10·50 23·32 5·96
			10·50	3·78	215	120·0	29·28 3·78 25·50 10·50

erect another staff beyond you, in the same line, and at the same distance, as the first, that the instrument may be equally distant from each staff; then direct the telescope towards the first staff,



and sign to a person holding it, to move the vane higher or lower, until the wire placed across it coincides with the intersection of the cross wires in the telescope; he is then to note the height marked by the wire on the staff, which suppose to be 4·69 feet. Now turn the telescope about, and point it towards the second staff, and direct that its vane be raised or lowered, as the former was, until the cross wire is intersected by the wires of the telescope; it must then be likewise read off; and suppose the reading to be 9·93 feet.

Having completed the first level, let the first staff take the place of the second, and the second to be set up further on in the required direction, as at B. Then, midway between them, set up your level, and direct it to the first staff, and then to the second, making the necessary observations, as before, when the staves being read off, the operation is completed. Let us suppose the first to read 0·64 feet, and the second, 11·88 feet; the work will then stand thus:—

Reading of the first staff (or back station)	Feet.	Reading of the second staff (or forward station)	Feet.
First reading . . .	4,69	First reading . . .	9,93
Second reading . .	0,64	Second reading . .	11,88
Sum . . .	5,33	Sum . . .	21,81

The difference of these sums shows that the ground at B is 16·48 feet, or 16 feet 5·76 inches lower than at A.

By continuing the above process, the operation of levelling may be carried on for many miles, the relative height of every station being determined. Also, if the height from the ground of the centre of the levelling telescope be taken at each place at which it is set up, the relative height of that spot will also be determined.

In common levelling operations, it is not usual to be particular about placing the instrument in the centre between the staves, also F E is the excess of height at F; G H, that at G, &c. The difference, it is evident, is always equal to the excess of the secant of the arc of distance above the radius of the earth.

"Now the difference C D, between the true and apparent level at any distance B C or B D, may be found thus: by a well-known property of the circle, $2\ AC + CD : BD :: BD : CD$. But because the diameter of the earth is so great with respect to the line C D, at all distances to which an operation of levelling commonly extends, 2 A C may be taken for $2\ AC + CD$ in this proportion without sensible error. The proportion then will be $2\ AC : BD :: BD : CD$;

$$\text{whence } DC \text{ is} = \frac{BD^2}{2\,AC} \text{ or } \frac{BC^2}{2\,AC} \text{ nearly;}$$

that is, the difference between the true and apparent level, is equal to the square of the distance between the places, divided by the diameter of the earth; and consequently it is always proportional to the square of the distance."

Now the diameter of the earth being nearly 41,796,480 feet, or 7916 miles; if we first take B C equal 1 mile, then the excess $\frac{BC^2}{2\,AC}$ is $\frac{1}{7916}$ of a mile, which is 8,004 inches, for the height of the apparent above the true level at the distance of one mile. Otherwise, if to the arithmetical complement of the logarithm of the diameter, or 2,3788603, we add double the logarithm of the distance in feet, we shall obtain the logarithm of the difference of the true and apparent level in decimals of the same, to be subtracted from the height given by the instrument to reduce it to the true level. In this manner the corrections have been computed contained in Table I., which shows the difference in decimals of a foot between the true and apparent level, corresponding to any distance from 20 to 5000 feet.

The usual method of obtaining the difference of level between any two places, is by a tangent, whose point of contact is exactly in the middle of the level line: this method may be practised without regarding the difference between the apparent and true level; for it is clear, that if from the same station, two points of sight be observed equally distant from the eye of the observer, they will be also equidistant from the centre of the earth. Thus, et the instrument be placed at B, (see the last figure,) equally istant from the station staves at C and I, the two points of ght, D and J, marked upon them by the tangent, J D (or J H,) ll be level points, and the difference in height between C D d I J, will show how much the one place is higher than most practical purposes, thus securing greater certainty and expedition in the work; for it not unfrequently happened in using the old staves, that when, by a succession of signals, the staff-holder had nearly brought the wire of the vane to coincide with that of the telescope, he would, in his attempt to perfect it, remove the vane further from coincidence than at first; and we have been informed, that on one occasion the man held the staff upside down, which introduced an error of several feet. To obviate these difficulties, Mr. Gravatt proposed, that the observer should read the staff himself, which is now successfully practised.

The newly-constructed staff consists of three parts, which pack together for carriage in a neat manner, and when opened out for use form a staff seventeen feet long, jointed together, something after the manner of a fishing rod: the whole length is divided into hundredths of a foot, alternately coloured black and white, and occupying half the breadth of the staff; but for distinctness, the lines denoting tenths of feet are continued the whole breadth, every half foot or five tenths being distinguished by a conspicuous black dot on each side. The whole contrivance is very successful, and in some late levelling operations in which we were engaged, we were able perfectly to read the staff, with only a fourteen-inch level, at the distance of twelve chains.

ON LEVELLING.

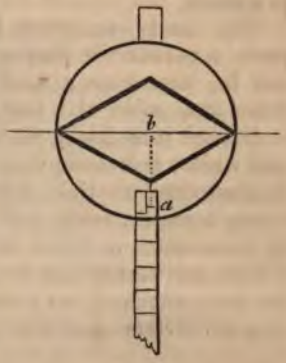
"Levelling is the art of finding a line parallel to the horizon at one or more stations, to determine the height or depth of one place with respect to another. Two or more places are on a true level, when they are equally distant from the centre of the earth. Also, one place is higher than another, or above the level of it, when it is further from the centre of the earth; and a line equally distant from that centre in all its parts, is called a line of true level. Hence, because the earth is round, that line must be a curve, and make a part of the earth's circumference, or at least be parallel to it; as the line I B C F G, which has all its points equally distant from A, the centre of the earth; considering it as a perfect sphere.

"But the line of sight, B, D,

ment is great, requires to be corrected for the curvature of the earth. The method of computing this correction will be presently shown.

TROUGHTON'S LEVELLING-STAVES.

These consist of three sliding rods of mahogany, each about four feet long, and they are divided into feet, &c., as those which have just been described. The sliding vane is circular, having at the lower edge a square aperture, one side of which is bevelled; and a line on the bevelled side denotes the reading of the staff. The face of the vane is made of white holly, with an inlaid lozenge of ebony, forming at once a conspicuous object, and one easy of bisection. A circular spirit-level is attached to the top of the hindermost rod, to guide the assistant in holding it perpendicular.



In levelling, the vane must be moved up or down, until the horizontal wire of the telescope bisects the acute angles of the lozenge, or in other words passes through its horizontal extremities, as shown in the figure.

The line on the bevelled edge at *a* (as before stated) denotes the reading of the staff; therefore, a piece equal in length to the distance, *a b*, is cut off from the bottom of the staff, or rather the divisions commence at that number of inches above 0.

When the observation requires that the vane be raised to a greater height than four feet, the object is effected by leaving it at the summit of the rod in front, and then sliding this rod up upon the one which is immediately behind it, this will carry the vane up to eight feet; and from that to twelve may be obtained by similarly sliding the second upon the third rod. In the latter steps, the reading is at the side of the staff, the index division remaining stationary, and at four feet from the ground, a circumstance which affords greater facility in reading off.

THE NEW LEVELLING-STAVES.

Several years ago, William Gravatt, Esq., had constructed for his own use a new kind of levelling-staff, which now appears likely to come into general use. They have no vane to slide up and down, but the face of each staff is made broad enough to in complete adjustment (under which term curvature and refraction are included), when the reading on staff a was 4·01, the readings on b and c should have been respectively 0·82 and 2·12.

The instrument therefore points upwards, the error at b being 0·21, and the error at c, 0·95: now, were the bubble only in error, (as is supposed in all other methods of adjustment,) the error at c ought to be four times as great as at b, but 4 × 0·21 = 0·84 only, there is an error, therefore, of 0·95 — 0·84 = 0·11 not due to the bubble.

For the purpose of correcting this error, (and be it remembered contrary to former practice, for this purpose only,) we must use the capstan-headed screws at the eye end of the telescope, and neglecting the actual error of level, we are only to make the error at b one-fourth that of c.

After a few trials, whilst the reading at a continued 4·01, the reading on b became 0·75, and that on c, 1·84.

Now 0·82 — 0·75 = 0·07, and 2·12 — 1·84 = 0·28.

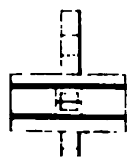
And as 4 × 0·07 = 0·28, the telescope is now adjusted for collimation.

All that remains to be done, is to raise the object end of the telescope by means of the parallel plate-screws, until the staff at c reads 2·12, and then, by means of the nuts which adjust the bubble-tube to bring the bubble into the centre of its run.

The operation of collimating, when once performed upon levels on Mr. GRAVATT's construction, will scarcely ever need being repeated.

OF THE LEVELLING STAVES.

Two mahogany station-staves generally accompany the spirit-level; they consist of two parts, capable of being drawn out when considerable length is required. They are divided into feet and hundredths, or feet, inches, and tenths, and have a sliding vane, with a wire placed across a square hole in the centre, as shown in the annexed figure: this vane being raised or lowered by the assistant, until the cross-wire corresponds with the horizontal wire of the telescope, the height of the wire in the vane, noted on the staff, is the height of the apparent level above the ground at that place.



When both the staves are used, they should be set up at equal distances on each side of the spirit-level: the difference of the heights of their vanes

B, placed on the stake *b*; call the two readings, A′ and B′; then, although the instrument be out of adjustment, yet the points read off will be equidistant from the earth's centre, and consequently level.

"Now remove the instrument to a point half way between *b* and *c*. Again read off the staff B, and read also a staff placed on the stake *c*, which call staff C (the one before, called A, being removed into that situation). Now by adding the difference of the readings on B (with its proper sign) to the reading on C, we get three points, say A′, B′, and C′, equidistant from the earth's centre, or in the same true level.

"Place the instrument at any short distance, say half a chain beyond A, and, using the bubble merely to see that you do not disturb the instrument, read all three staffs, or, to speak more correctly, get a reading from each of the stakes, *a*, *b*, *c*: call these three readings, A″ B″ C″. Now, if the stake *b*, be half way between *a* and *c*, then ought C″— C′—(A″—A′) be equal 2 [B″—B′—(A″—A′)]; but if not, alter the screws which adjust the diaphragm, and consequently the horizontal spider-line, or wire, until such be the case; and then the instrument will be adjusted for collimation.

"To adjust the spirit-bubble, without removing the instrument, read the staff, A, say it reads A‴, then adding (A‴—A′) with its proper sign to B′ we get a value, say B‴.

"Adjust the instrument by means of the parallel plate-screws, to read B‴ on the staff B.

"Now, by the screws attached to the bubble-tube, bring the bubble into the centre of its run.

"The instrument will now be in complete practical adjustment, for level, curvature, and horizontal refraction, for any distance not exceeding ten chains, the maximum error being only $\frac{1}{1000}$th of a foot."

EXAMPLE.

The instrument being placed half way between two stakes, *a* and *b*, (at one chain from each,) the staff on *a* or A′ read 6·53, and staff on *b* or B′ read 3·34, placing the instrument half way be- ween the stakes *b* and *c*, (three chains from each) the staff on *b* ead 4·01, and the staff on *c* read 5·31.

Hence, taking state *a* as the datum, we have

Stake. Above Datum.

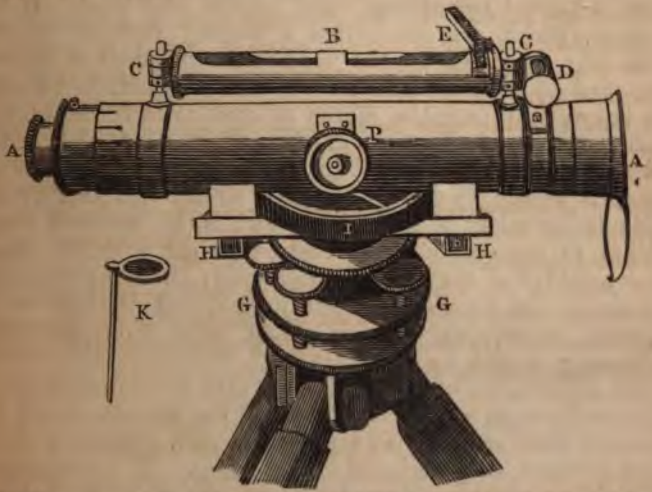
or boggy ground, where the least movement of the observer will materially alter the level of the instrument, as by keeping both eyes open, with a little practice, the cross-wires, the bubble, and the staff, can be all three seen at the same time, and by a slight pressure of the hand upon one of the level-legs, any displacement of the bubble may be corrected. The parallel plates and screws, G G, are similar in every respect to those of the former-described instruments. We may remark, that it is convenient to have one of the screws resting in a notch, or Y, fixed on the lower plate exactly over one of the legs; then, by giving motion to that leg only, after the other two are fixed in the ground, the instrument can be set up so nearly level, that a very small motion of the parallel plate-screws will be required to perfect it.

H H represent two capstan-screws, the same as in TROUGHTON's level, and for a similar purpose, viz., to make the spirit-bubble maintain a central position in its tube, while the instrument is turned completely round on the staff-head. I, is the compass, which contains either a floating card or graduated silver ring, mounted on the needle, the divisions of which are magnified by a lens, K, which slides in a socket, (not shown in the figure,) affording the means of reading to 10 minutes of a degree: the rapid vibrations of the card or needle are checked and speedily brought to rest by a contrivance, in which a spiral spring is moved by a milled-headed screw; this acts upon the needle independent of its centre, which is thus secured from its liability in the ordinary construction to get blunted, whereby the sensibility of the needle is destroyed: the same milled-head will clamp the needle when not in use, and prevent the mischievous consequences which would arise from suffering it continually to play upon its centre.

The adjustments of this instrument may be examined and rectified in the same manner as described for TROUGHTON's level, but much more correctly as described by Mr. GRAVATT himself, which we have his permission for inserting. By his method the instrument may be so adjusted, that any imperfections in the slide or tube of the telescope, arising from their not being straight, may not in the least cause the intersection of the cross-wires to deviate from the optical axis of the telescope in its motion, during adjustment for distinct vision.

To examine and correct the Collimation.

for distinct vision of a distant object by the milled-head P. The spirit-level is represented at B, placed above the telescope, and attached to two rings passing round it by the capstan-headed screws C C, which are the means of adjusting the air-bubble of the level for parallelism with the line of collimation. D represents a small level placed across the telescope at right angles to the principal level C C; it is very convenient in setting the instrument up approximately level by means of the legs only, which saves time, and also the wear of the parallel plate-screws. (Practical men are aware of the uncertainty in judging by the eye alone when the instrument is set nearly level, especially on the side of sloping ground, and duly appreciate the application of the cross-level, by which their valuable time and the wear of their instruments are saved.) Having directed the sight to the staff, and adjusted for distinct vision, the two levels at once show which of the screws require touching, to perfect the level, before noting the observation.



A mirror, mounted by a hinge-joint on a spring piece of brass, is placed on the telescope, as represented at E; its use is to reflect the image of one end of the air-bubble (in the principal level) to the eye, so that the observer (after having carefully adjusted his level) can, at the same time that he is reading the staff, see that the instrument retains its position, by noticing if the reflected end of the air-bubble coincide with the proper hould be at least as sensible as that of the instrument under djustment, otherwise this method will be very uncertain.

It would be advisable, when the instrument is in perfect adustment, to fix a level mark on some permanent spot, as a wall, c., to which the level may be from time to time referred, by imply setting it up at a certain height from the ground, and ooking through the telescope at the mark; any error in collimaion will be immediately detected, and may be corrected by the ollimation-screws only.

The Method of approximately determining Distances by the Micrometer Scale.

First ascertain the value of the divisions on the scale, and rrange them in a tabular form; to do which, measure off one hain's length from the object end of the telescope, and having et up a staff there, observe how many divisions and tenths of a livision on the scale are occupied by the whole length of the taff, or any part of it. Do the same when it is placed at 2, 3, , &c., chains, as far as 10, and place the results in a table.

Now to determine any distance, set up the same staff, or one f equal length, at the distant spot; observe how many divisions nd tenths on the scale its whole length subtends, and take from our table the nearest number of divisions and parts, which make he first term of an *inverse proportion*, the second term is the umber of chains corresponding thereto, the third the observed livisions and parts, and the fourth will be your answer, viz., the listance required.

In making the observations, great care is required in estinating the number of divisions, &c., subtended on the scale by he distant staff, as an error of half a division would occasion a onsiderable error in the final result.

MR. GRAVATT'S LEVEL.

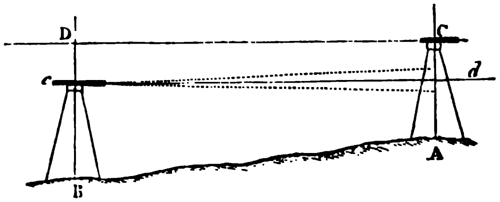
ane must be lowered half that quantity, and the collimation-crews moved to correct the other half; if below the line *c d*, the ifference will be less than two feet, and the vane must be raised alf that quantity, &c.

Another method of proving the adjustment of the line of ollimation is as follows:—Let there be two staves held upright t any convenient distance from each other; call one staff A, nd the other B; then place the instrument nearly in a line with he staves, at about one or two chains' length beyond that called A, and having set it level by the parallel plate-screws, read off oth the staves; having done this, remove the instrument to bout the same distance from the staff B, set it level, and again ead the staves: now, if half the sum of the readings upon the taff A, and also of those upon the staff B, be taken, they will ive two points upon the staves that are truly horizontal, by which, or by any other points equidistant therefrom, as may best uit the height at which the instrument is set up, so as to be seen n the field of the telescope, the horizontal wire may be adjusted, that is, moved by its proper screws, so as to coincide with both those points (or readings on the staves).

A third method of adjustment is by means of a sheet of water, nd when practicable, is both convenient and accurate: thus, at the distance of a few chains, drive two stakes close to the water's edge, so that their upper ends may be *even* with the surface of the water; let the level be set up over one of the stakes, and a staff held perpendicular upon the other. Now, having measured the height of the centre of the telescope above the stake over which it is placed, it remains but to move the horizontal wire, ither up or down, till it points out exactly the same height on he staff, if it does not already do so.

The adjustment of TROUGHTON's level may also be effected by mploying as a *collimator* the telescope of a theodolite, or Y vel, in the following manner:—First ascertain that the adjust- ent of the collimating telescope is perfect; then set both in- uments up with their telescopes nearly at the same height, and ir object glasses opposed to each other, so that, upon placing eye to either instrument, you may be able to look through h telescopes at once; or, to speak more correctly, you must the image of the field of the further telescope with its cross- s distinctly. Both instruments must be carefully levelled, the telescopes adjusted to about the focus for distinct vision remote object: this done, look through spirit-bubble preserve its position while it is turned round horizontally on the staff-head. The adjustment of the level is effected by correcting half the observed error by the capstan-screws, *e f*, which attach the telescope to the horizontal bar, and the other half by the parallel plate-screws: the capstan-screws, *e*,*f*, have brass covers to defend them from injury or accidental disturbance, but admit their adjustment when necessary.

The spirit-level itself has no adjustment, being firmly fixed in its cell by the maker, and therefore the line of collimation must be adjusted to it, by means of two screws, near the eye-end of the telescope: the manner of doing this is as follows:—Set up the instrument on some tolerably level spot of ground, and after levelling the telescope by the parallel plate-screws, direct it to a staff held by an assistant at some distance (from ten to twenty chains); direct him by signals to raise or depress the vane, until its wire coincides with the horizontal wire of the telescope (or central division of the micrometer scale;) now measure the height of the centre of the telescope above the ground, and also note the height of the vane on the staff; let, for example, the former be four feet and the latter six, their difference shows that the ground over which the instrument stood is two feet higher than where the staff is placed. Next make the instrument and staff change places, and observe in the same manner as before, and if it gives the same difference of level, the instrument is correct; if otherwise, take half the difference between the results, and elevate or depress the vane that quantity, according as the last observation gives a greater or less difference than the first. Again, direct the telescope to the staff, and make the coincidence of the horizontal wire and that on the vane perfect, by turning the collimation-screws.



Suppose the instrument to be set up at A, and the staff at
C D will be the line of sight. A C the height of the instrum
height of the vane = 6 feet; their differe

Y level and the theodolite). On the top of the telescope, and partly imbedded within its tube, is the spirit-level, *c d*, over which is supported the compass-box, C, by four small pillars; thus admitting the telescope to be placed so close to the horizontal bar, *a b*, that it is much more firm than in the former instrument. The bubble of the level is sufficiently long for its ends to appear on both sides of the compass-box; and it is shown to be in the middle by its coinciding with scratches made on the glass tube as usual.

The wire plate (or diaphragm) is generally furnished with three threads, two of them vertical, between which the station-staff may be seen; and the third, by which the observation is made, is placed horizontally. Sometimes a pearl micrometer-scale is fixed perpendicularly on the diaphragm instead of wires. This consists of a fine slip of pearl, with straight edges, one of which is divided into a number of parts, generally hundredths or two-hundredths of an inch; and it is so fixed, that the divided edge intersects the line of collimation, the central division indicating the point upon the staff where the observed level falls. The scale itself may be employed in approximately determining distances, as will be shown hereafter. It is also very useful in roughly estimating equal distances from the instrument in any direction. Thus, if a man in attendance holds up a staff at any distance, and the observer, looking at it through the telescope, notices how many divisions of the micrometer-scale the staff appears to subtend, then, if the man moves in any other direction, retiring until the same staff appears to cover an equal number of divisions, he will be at the same distance from the instrument as before. We have seen a successful application of a delicate wire micrometer to a levelling telescope precisely similar to those applied to astronomical instruments, by means of which distances can be determined with great precision, and will fail only when the wind is too high to permit the instrument or staff to remain steady.

The telescope is generally constructed to show objects inerted; and as such a telescope requires fewer glasses than one hich shows objects erect, it has the advantage in point of brilancy; and when an observer is accustomed to it, the apparent version will make no difference to him. A diagonal eye-piece, wever, generally accompanies the instrument, and by it obts can be seen in their natural position. A cap is adapted to object-end of the telescope, to screen the glass from the rays he sun, or from the rain: when the cap is used, it should be n forwards as much as possible.

he requisite adjustments for this instrument are the

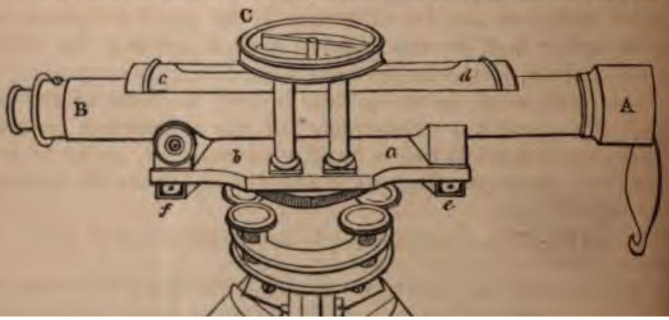
the air-bubble of the level settles in the middle of its tube; then turn the instrument half round upon the vertical axis, so that the contrary ends of the telescope may be over the same two screws, and if the bubble again settles in the middle all is right in that position; if not, half the error must be corrected by turning the screw, B, and the other half by the two parallel plate-screws over which the telescope is placed. Next turn the telescope a quarter round, that it may lie over the other two screws, and make it level by moving them, and the adjustment will be complete.

Before making observations with this instrument, the adjustments should be carefully examined and rectified, after which the screw B should never be touched; the parallel plate-screws alone must be used for setting the instrument level at each station, and this is done by placing the telescope over each pair alternately, and moving them until the air-bubble settles in the middle. This must be repeated till the telescope can be moved quite round upon the staff-head, without any material change taking place in the bubble.

A short tube, adapted to the object-end of the telescope, will occasionally be found useful in protecting the glass from the intensity of the sun's rays, and from damp in wet weather.

TROUGHTON'S IMPROVED LEVEL.

This modification of the instrument has a very decided advantage over the Y level, inasmuch, as in its construction it is more compact, and the adjustments when once made are less liable to be deranged; although, to a person unused to the instrument, they will at first appear more tedious to accomplish.



of the cylindrical rings on which the telescope turns; secondly, to render the level parallel to this axis; and lastly, to set the telescope perpendicular to the vertical axis, that the level may preserve its position while the instrument is turned quite round upon the staves.

To Adjust the Line of Collimation.

The eye-piece being drawn out, to see the wires distinctly, direct the telescope to any distant object, and by the screw, A, adjust to distinct vision;* bring the intersection of the cross wires to coincide with some well-defined part of the object, then turn the telescope round on its axis as it lies in the Y's, and observe whether the coincidence remains perfect during its revolution: if it does, the adjustment is correct, if not, the wires must be moved one-half the quantity of error, by turning the little screws near the eye-end of the telescope, one of which must be loosened before the opposite one is tightened, which, if correctly done, will perfect this adjustment.

To set the Level parallel to the Line of Collimation.

Move the telescope till it lies in the direction of two of the parallel plate-screws, (the clips which confine the telescope in the Y's being laid open,) and by giving motion to the screws, bring the air-bubble to the middle of the tube, shown by the two scratches on the glass. Now reverse the telescope carefully in its Y's, that is, turn it end for end; and should the bubble not return to the centre of the level as before, it shows that it is not parallel to the optical axis, and requires correcting. The end to which the bubble retires must be noticed, and the bubble made to return one-half the distance by the parallel plate-screws, and the other half by the capstan-headed screw at the end of the level, when, if the halves have been correctly estimated, the air-bubble will settle in the middle in both positions of the telescope. This and the adjustment for the collimation generally require repeated trials before they are completed, on account of the difficulty in estimating exactly half the quantity of deviation.

To set the Telescope perpendicular to the vertical Axis.

Place the telescope over two of the parallel plate-screws, and move them (unscrewing one while screwing up the other) until

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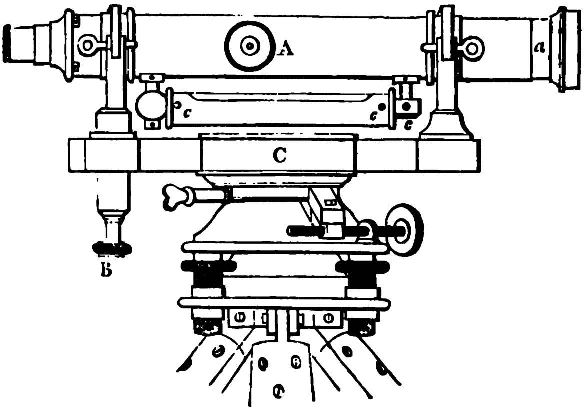
* The eye-piece must first be drawn out until the cross wires are perfectly well

LEVELLING INSTRUMENTS.

THE Y SPIRIT-LEVEL.



The above figure represents this instrument; it has an achromatic telescope, mounted in Y's like those of the theodolite, and is furnished with a similar system of cross wires for determining the axis of the tube, or line of collimation. By turning the milled-headed screw, A, on the side of the telescope, the internal tube, *a*, will be thrust outwards, which carrying the object-glass, it is by this means adjusted to its focal distance, so as to show a distant object distinctly.

The tube, *c c*, carrying the spirit-bubble, is fixed to the under side of the telescope by a joint at one end and a capstan-headed screw at the other, which sets it parallel to the optical axis of the telescope; at the opposite end is another screw, *e*, to make it parallel in the direction sidewise. One of the Y's is supported in a socket, and can be raised or lowered by the screw, *B*, to make the telescope perpendicular to the vertical axis. Between supports is a compass-box, C, (having a contrivance to off its centre when not in use): it is

The proof of the accuracy of a number of horizontal angles, f they quite surround the station from whence they are taken, s to add them altogether, and their sum, if correct, will be 360°. f they are taken at several stations, consider them as the internal ngles of a geometrical figure, and the lines connecting the tations as the sides of such figure; then, if the figure has three ides, their sum will = 180°, if four sides, = 360°; if more than our, multiply 90° by double the number of sides, and subtract 60° from the product; the remainder will be the sum of the nternal angles.

The altitude and azimuth of a celestial object may likewise be bserved with the theodolite, the former being merely the eleva- ion of the object taken upon the vertical arc, and the latter its orizontal angular distance from the meridian.

The following particulars refer to the engraving at page 21.

The figure at page 21 shows the triangular plate, or base, upon hich the instrument is set when in use. A is the screw where- y the plate is attached to the hêad of the tripod staff, or legs of e instrument. D shows the edge of the lower or main plate, at is so screwed on to the staff head. B, B, B, is the upper te, which slides on the surface of the lower one, D; each gle of the upper plate is perforated to admit of the passing of flanged heads of the footscrews of the tripod to cells made in lower plate for their reception, and when the instrument is s dropped into its place on the stand, it is there secured by ing the upper plate into the position shown in the above re, whereby the narrow part of the perforations are brought the heads or flanges of the foot-screws, and they are then ined in their places. The two plates are thus kept in the tion now described, by the catch C, which acts with a spring, prevents their having any lateral motion. By the above ivance the theodolite is readily attached to the stand, or *ersâ.*

alike,* the mean of them should still be taken, unless one vernier alone is used, which should never be the case; therefore it matters not at what part of the lower, the upper limb is clamped, provided the angle is read off every time an object is bisected, for the difference between any two readings will be the angle subtended by the objects observed.

It would appear from the above statement, that it is not necessary for the lower horizontal plate to have any motion at all, which is certainly the case when angles are simply to be measured; but its use is important, as it gives us the means of repeating the measure of any angle we may wish to determine with great accuracy, it being evident that a mean of a number of observations will give a more correct result than a single one. To repeat an angle, therefore, after making the second bisection as above directed, leave the upper plate clamped to the lower, and release the clamp of the latter; now move the whole instrument (bodily) round towards the first object, till the cross-wires are in contact with it; then clamp the lower plate firm, and make the bisection with the lower tangent-screw. Leaving it thus, release the upper plate, and turn the telescope towards the second object, and again bisect it by the clamp and slow motion of the upper plate. This will complete one repetition, and if read off, the difference between this and the first reading will be double the real angle. It is, however, best to repeat an angle four or five times; then the difference between the first and last readings (which are all that it is necessary to note) divided by the number of repetitions will be the angle required.

The magnetic bearing of an object is taken, by simply reading the angle pointed out by the compass-needle, when the object is bisected; but it may be obtained a little more accurately by moving the upper plate (the lower one being clamped) till the needle reads zero, at the same time reading off the horizontal limb; then turning the upper plate about, bisect the object and read again: the difference between this reading and the former will be the bearing required.

In taking angles of elevation or depression, it is scarcely necessary to add, that the object must be bisected by the horizontal wire, or rather by the intersection of the wires, and that after observing the angle with the telescope in its natural position, it should be repeated with the telescope turned half round in its Y's, that is, with the level uppermost; the mean of the two measures will neutralize the effect of any error that may exist in the line of collimation.

to write a treatise upon that subject, but in addition to what we here insert, some further particulars will be found in the Appendix, where we purpose explaining the manner of surveying roads, boundaries, &c., in connection with the method of using a circular protractor. Confining ourselves therefore to the manner of measuring angles by its assistance, we observe, that the instrument being placed exactly over the station from whence the angles are to be taken, by means of the plumb-line suspended from its centre, it must be set level by the parallel plate-screws, *b b*, &c., (page 15) bringing the telescope over each pair alternately; one must be unscrewed while its opposite one is screwed up, until the two spirit-levels on the vernier plate steadily keep their position in the middle of their tubes, while the instrument is turned quite round upon its staff-head, when it will be ready for commencing operations. (We are now supposing that the adjustments before described have been carefully examined and rectified, otherwise the observations will be good for nothing.) First, clamp the lower horizontal limb firmly in any position, and direct the telescope to one of the objects to be observed, moving it till the cross-wires and object coincide; then clamp the upper limb, and by its tangent-screw make the intersection of the wires nicely bisect the object; now read off the two verniers, the degrees, minutes, and seconds of (either) one, which call A,* and the minutes and seconds only of the other, which call B, and take the mean of the readings thus:—

$$\begin{array}{rlll} A & = 142^\circ & 36' & 30'' \\ B & = \text{,,} & 37 & 0 \\ \hline \text{Mean} & = 142 & 36 & 45 \\ \hline \end{array}$$

Next release the upper plate and move it round until the telescope is directed to the second object (whose angular distance from the first is required), and clamping it, make the cross-wires bisect this object, as was done by the first; again read off the two verniers, and the difference between their mean, and the mean of the first reading, will be the angle required.

Some persons prefer making their first reading = zero, by clamping the upper to the lower plate of 360°, and bisecting the first object by the clamp and slow motion of the lower limb; then their second reading will be the absolute angle subtended by the two objects: but as both verniers seldom read exactly rest upon low supports, (only one of them, D, being visible in the figure), carried out from the centre, on each side, by a flat horizontal bar, F, to which a spirit-level, G, is attached for adjusting the axis to the horizontal plane. The vertical angles are read off on two arcs of circles, H H, which have the horizontal axis as their centre, and being attached to the telescope, move with it in a vertical plane. An index, upon the same centre, carries two verniers, I I, and it has a spirit-level, K, attached to it, by which the index can be set in a horizontal position, so that whatever position the telescope, and consequently the graduated arcs, may have, when an observation is made, the mean of the two readings will denote the elevation or depression of the object observed, from the horizontal plane.

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* It would be better to have the letters A, B, &c., engraved over the verniers, making it a rule always to read the degrees from the one called A, which would

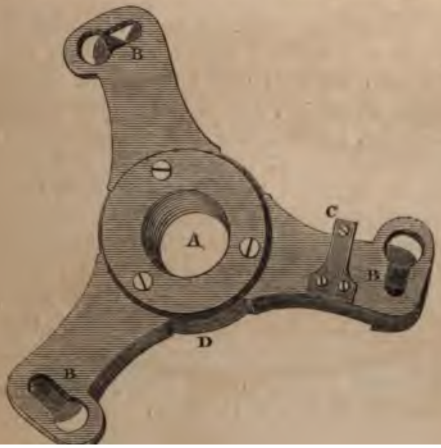
The following are the adjustments of this instrument: first, to set the instrument level: to accomplish this, bring the spirit-bubble, G, attached to the horizontal bar in a direction parallel to two of the foot-screws, and by their motion cause the air-bubble to assume a central position in the glass-tube; then turn the telescope, level, &c., half round, and if the bubble is not central, correct half the deviation by raising or lowering one end of the level itself, and the other half by the foot-screws, which in this instrument perform an office similar to that of the parallel plate-screws of the theodolite already described. Having perfected this part, turn the telescope a quarter round, and the level will be over the third foot-screw, which must be moved to set the level correct, and this part of the adjustment will be complete.

The line of collimation must be next attended to: direct the telescope to some well-defined object, and make the vertical wire bisect it; then turn the axis end for end, an operation which of course inverts the telescope, and if the object be not now bisected by the vertical wire, correct half the deviation by the collimating screws at the eye-end of the telescope, and the other half by giving motion in azimuth to the instrument, and this must be repeated till the adjustment is satisfactorily accomplished.

Finally, for the zero of altitude. Take the altitude or depression of an object with the vertical sector in reversed positions; half the sum will be its true altitude, or depression, and to this, let the verniers be set. Again carefully direct the telescope to the object, making the bisection by the screws which retain the index in a horizontal position, and finally correct the level by the adjusting screws at one of its ends.

ference. The index is formed with four radiating bars, *a*, *b*, *c*, *d*, having verniers at the extremities of three of them, for reading the horizontal angles, and the fourth carries a clamp to fasten the index to the edge of the horizontal limb, and a tangent-screw for slow motion. These are connected with the upper works which carry the telescope, and turning upon the same centre, show any angle through which the telescope has been moved. The instrument has also the power of repeating the measurement of an angle; for the horizontal limb being firmly fixed to a centre, movable within the tripod support, B, and governed by a clamp and tangent-screw, C, can be moved with the same delicacy, and secured with as much firmness, as the index above it. Large theodolites, when required, have the power of repeating given them, by means of a particular kind of stand, called a repeating table.

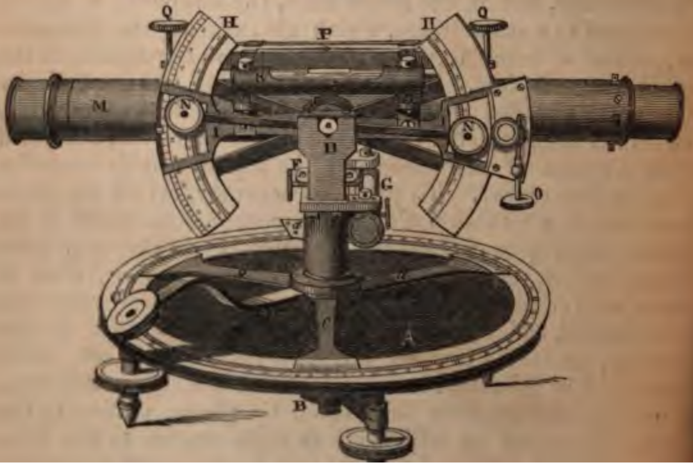
The tripod support, which forms the stand of the instrument, has a foot-screw at each extremity of the *arms* which form the tripod; the heads of the foot-screws are turned downwards, and have a flange (or shoulder) upon them, so that when they rest upon a triangular plate fixed upon the staff-head, another plate locks over the flange, and being acted upon by a spring, retains the whole instrument firmly upon the top of the staff, which is similar to that of the theodolite represented at page 15. The great advantage of the tripod stand is, that it can easily be disengaged from the top of the staff, and placed upon a parapet or other support, in situations where the staff cannot be used.



or that which is under the telescope, serves for adjusting the zero of altitude, or vernier of the vertical arc.

A second telescope is sometimes attached to the instrument beneath the horizontal limb; it admits of being moved, both in a vertical and horizontal plane, and has a tangent-screw attached for slow motion: its use is to detect any accidental derangement that may occur to the instrument whilst observing, which may be done by it in the following manner. After levelling the instrument, bisect some very remote object with the cross-wires of this second telescope, and clamp it firm; if the instrument is steady, the bisection will remain permanent whilst any number of angles are measured, and by examining the bisection from time to time, during the operation at the place where the instrument is set up, any error arising from this cause may be detected and rectified.

At the suggestion of Captain Everest, surveyor-general of India, several small theodolites, differing considerably in construction from that which we have been describing, have lately been made by Messrs. Troughton and Simms, for the great Indian survey. In principle they are similar to the theodolites of much larger dimensions, and consequently the whole of their essential adjustments are made in the same manner. We shall here give a description and engraving of this kind of instrument, with the particulars of its adjustments, which must be understood as equally applicable to the larger theodolites usually employed in extensive trigonometrical operations.



note the quantity of deviation as an index error, and apply it, plus or minus, to each vertical angle observed. This deviation is best determined by repeating the observation of an altitude or depression in the reversed positions, both of the telescope and the vernier plate: the two readings will have equal and opposite errors, one half of their difference being the index error. Such a method of observing angles is decidedly the best, since the mean of any equal number of observations taken with the telescope reversed in its Y's, must be free from the effects of any error that may exist in the adjustment of the vernier, or zero of altitude.

The theodolite, as constructed in the manner we have described, is not inconveniently heavy, as the diameter of the horizontal limb seldom exceeds five inches; but when the diameter is increased, the other parts must be made proportionably large and strong, and the instrument becomes too weighty and cumbersome to be easily carried from station to station. The object of increasing the dimensions, is to enable the instrument to furnish more accurate results, by applying a telescope of greater power, and by a more minute subdivision of the graduated arcs. With the increase of size, a small variation takes place in the construction, principally consisting in the addition of a second telescope, and in the manner of attaching the supports, K and L, (page 15) to the horizontal limb, to afford the means of adjusting the horizontal axis, and of course, making the telescope and vertical arc move in a vertical plane. In the smaller instruments this is done by construction, but in the larger ones, the supports, K and L, are attached to a stout frame, which also carries the compass-box, instead of being fixed as represented in our figure, to the upper horizontal plate. The frame is attached to the limb by three capstan-headed screws, forming an equilateral triangle, two of them lying parallel to the horizontal axis, and the third in the direction of the telescope; the adjustment is made by means of these screws. To prove its accuracy, set up the theodolite in such a situation that some conspicuous point of an elevated building may be seen through the telescope, both directly and by reflection, from a basin of water, or, what is better, of oil or quicksilver. Let the instrument be very correctly levelled, and if, when a vertical motion is given to the telescope, the cross-wires do not cut the object seen, both directly and by reflection, it is a proof that the axis is not horizontal; and its correction is effected by giving motion to the screws above spoken of, which are at right angles to the tele-

A similar proceeding will also put the vertical line correct, or rather, the point of intersection, when there are two oblique lines instead of a vertical one.

The second adjustment is that which puts the level attached to the telescope parallel to the rectified line of collimation. The clips, *i i*, being open, and the vertical arc clamped, bring the air-bubble of the level to the centre of its glass tube, by turning the tangent-screw, P; which done, reverse the telescope in its Y's, that is, turn it end for end, which must be done carefully, that it may not disturb the vertical arc, and if the bubble resume its former situation in the middle of the tube, all is right; but if it retires to one end, bring it back one half, by the screw *f*, which elevates or depresses that end of the level, and the other half by the tangent-screw, P: this process must be repeated until the adjustment is perfect; but to make it completely so, the level should be adjusted laterally, that it may remain in the middle of the tube when inclined a little on either side from its usual position immediately under the telescope, which is effected by giving the level such an inclination, and if necessary turning the two lateral screws at *g*; if making the latter adjustment should derange the former, the whole operation must be carefully repeated.

The third adjustment is that which makes the azimuthal axis, or axis of the horizontal limb, truly vertical.

Set the instrument as nearly level as can be done by the eye, fasten the centre of the lower horizontal limb by the staff-head clamp, H, leaving the upper limb at liberty, but move it till the telescope is over two of the parallel plate-screws; then bring the bubble of the level under the telescope, to the middle of the tube, by the screw P; now turn the upper limb half round, that is 180°, from its former position; then, if the bubble returns to the middle, the limb is horizontal in that direction; but if otherwise, half the difference must be corrected by the parallel plate-screws over which the telescope lies, and half, by elevating or depressing the telescope, by turning the tangent-screw of the vertical arc; having done which, it only remains to turn the upper limb forward or backward 90°, that the telescope may lie over the other two parallel plate-screws, and by their motion set it horizontal. Having now levelled the limb-plates by means of the telescope level, which is the most sensible upon the instrument, the other air-bubbles fixed upon the vernier plate, may be brought to the middle of their tubes, by merely giving motion to the screws which fasten them in their places.

The vernier of the vertical arc may now be attended to; it is correct if it points to zero when all the foregoing adjustments at a distance can be made to bisect the said small angle with more certainty than it can be bisected by a vertical wire. The screws adjusting the cross wires are shown at *m:* there are four of these screws, two of which are placed opposite each other, and at right angles to the other two, so that by easing one, and tightening the opposite one of each pair, the intersection of the cross wires may be placed in adjustment.

The object-glass is thrust outwards by turning the milled head, Q, on the side of the telescope, that being the means of adjusting it to show an object distinctly.

A brass plummet and line are packed in the box with the theodolite, to suspend from a hook under its centre, by which it can be placed exactly over the station from whence the observations are to be taken: likewise, if required, two extra eye-pieces for the telescope, to be used for astronomical observations: the one inverts the object, and has a greater magnifying power, but having fewer glasses possesses more light; the other is a diagonal eye-piece, which will be found extremely convenient when observing an object that has a considerable altitude; the observer avoiding the unpleasant and painful position he must assume in order to look through the telescope when either of the other eye-pieces is applied. A small cap containing a dark coloured glass is made to apply to the eye-end of the telescope, to screen the eye of the observer from the intensity of the sun's rays, when that is the object under observation. A magnifying glass mounted in a horn frame, a screw-driver, and a pin to turn the capstan-screws for the adjustments, are also furnished with the instrument.

The Adjustments.

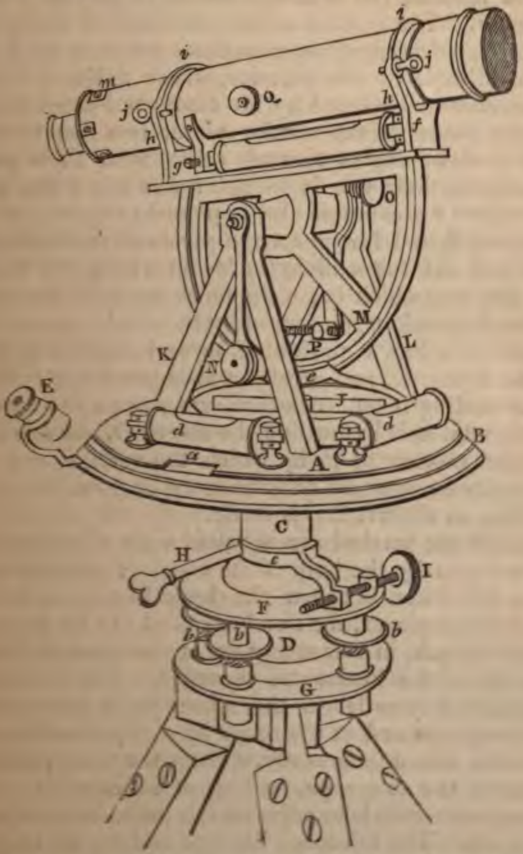
The first adjustment is that of the line of collimation; that is, to make the intersection of the cross wires coincide with the axis of the cylindrical rings on which the telescope turns: it is known to be correct, when an eye looking through the telescope observes their intersection continue on the same point of a distant object during an entire revolution of the telescope. The usual method of making this adjustment is as follows:

First, make the centre of the horizontal wire coincide with some well-defined part of a distant object; then turn the telescope half round in its Y's till the level lies above it, and observe if the same point is again cut by the centre of the wire; if not, move the wire one half the quantity of deviation, by turning two of the screws at *m*, (releasing one, before tightening the other,) exactly than can be done by the hand alone, the whole instrument, when thus clamped, can be moved any small quantity by means of the slow-motion screw, I, which is attached to the upper parallel plate. In like manner the upper or vernier plate can be fixed to the lower, in any position, by a clamp, (in the plate this clamp is concealed from view) which is also furnished with a slow motion, the screw of which is generally called the tangent-screw. The motion of this limb, and of the vertical arc, hereafter to be described, is sometimes effected by a rack and pinion; but this is greatly inferior, where delicacy is required, to the slow motion produced by the clamp and tangent-screw.

Upon the plane of the vernier plate, two spirit-levels, *d d*, are placed at right angles to each other, with their proper adjusting screws: their use is to determine when the horizontal limb is set level: a compass also is placed at J.

The frames K and L support the pivots of the horizontal axis of the vertical arc (or semicircle) M, on which the telescope is placed. The arm which bears the microscope N, for reading the altitudes or depressions, measured by the semicircle, and denoted by the vernier, *e*, has a motion of several degrees between the bars of the frame, K, and can be moved before the face of the vernier for reading it off. Another arm clamps the opposite end of the horizontal axis by turning the screw, O, and has a tangent-screw of slow motion at P, by which the vertical arc and telescope are moved very small quantities up or down, to perfect the contact when an observation is made.

One side of the vertical arc is inlaid with silver, and divided to single minutes by the help of its vernier; and the other side shows the difference between the hypothenuse and base of a right-angled triangle, or, the number of links to be deducted from each chain's length, in measuring up or down an inclined plane, to reduce it to the horizontal measure. The level, which is shown under and parallel to the telescope, is attached to it at one end by a joint; and at the other by a capstan-headed screw, *f*, which being raised or lowered, will set the level parallel to the optical axis of the telescope, or line of collimation; the screw, *g*, at the opposite end, is to adjust it laterally, for true parallelism in this respect. The telescope has two collars, or rings, of bell metal, ground truly cylindrical, on which it rests in its supports, *h h*, called Y's, from their resemblance to that letter; and it is confined in its place by the clips, *i i*, which may be opened by removing the pins, *j j*, for the purpose of reversing the telescope, or allowing it a circular motion round its axis, during the ad-socket at D, and are set firm and parallel to each other, by four milled-headed screws, three of which, *b b b*, are shown in the figure: these turn in sockets fixed to the lower plate, while their heads press against the under side of the upper plate, and being set in pairs, opposite each other, they act in contrary directions; the instrument by this means is set up level for observation.



Beneath the parallel plates is a female screw adapted to the staff head, which is connected by brass joints to three mahogany legs, so constructed that when shut up they form one round staff, secured in that form for carriage by rings put on them; and when opened out, they make a very firm stand, be the ground ever so uneven.

in the direction of other fixed points, and they ought also to intersect in the same point.

In this manner the plane-table may be employed for filling i the details of a map: setting it up at the most remarkable spots and sketching by the eye what is not necessary should be mor particularly determined, the paper will gradually become a representation of the country to be surveyed.

THE THEODOLITE.

As an angular instrument, the theodolite has from time to tim received such improvements, that it may now be considered a the most important one employed in surveying. Instruments o this kind, of the best construction, may to a certain extent be used as altitude and azimuth instruments; and several astronomical operations, such as those required for determining the time, the latitude of place, &c., may be performed by them, and to a degree of accuracy sufficient for most of the purposes that occur in the ordinary practice of a surveyor.

There are various modes of constructing theodolites to suit the convenience or the views of purchasers; but we shall confine ourselves to a description of one of the most perfect, as a person acquainted with the details of its adjustments and use will find no difficulty in comprehending those of others.

Description of the Theodolite.

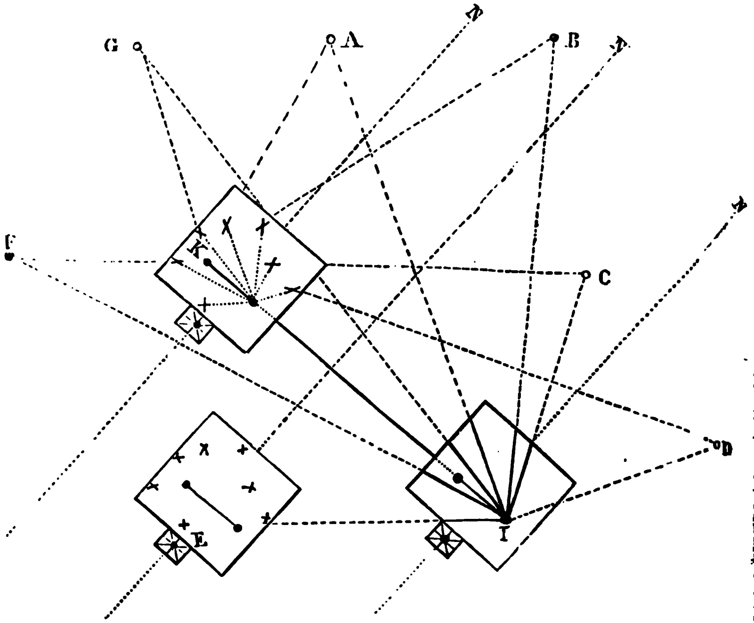
This instrument (as represented in the next page) consists of two circular plates, A and B, called the horizontal limb, the upper or vernier plate, A, turning freely upon the lower, both having a horizontal motion by means of the vertical axis, C. This axis consists of two parts, external and internal, the former secured to the graduated limb, B, and the latter to the vernier plate, A. Their form is conical, nicely fitted and ground into each other, having an easy and a very steady motion; the external centre also fits into a ball at D, and the parts are held together by a screw at the lower end of the internal axis.

The diameter of the lower plate is greater than that of the upper one, and its edge is chamfered off and covered with silver, to receive the graduations: on opposite parts of the edge of the upper plate, or 180° apart, a short space, *a*, is also chamfered forming with the edge of the lower plate a continued inclin plane: these spaces are likewise covered with silver, and fo the verniers. The lower limb is usually graduated to thirt minutes of a degree, and it is subdivided by the vernier to singl minutes, which being read off by the microscope, E, half, or ev to B, and draw the line I B; and so proceed with whatever objects are visible from the station, drawing lines successively in the direction of C D E, &c., taking care that the table remains steady during the operation.

This done, remove the instrument to the station K, and placing the edge of the index along the line I K, turn the table about till the sights are directed to the station I, which if correctly done, the compass-needle will point to the same bearing as it did at the former station (in our example it was set to the meridian). Now remove the needle from I, and fix it in the point K; lay the edge of the index against the needle, and direct the sights in succession to the points A B C, &c., drawing lines from the point K, in their several directions, and the intersection of these lines, with those drawn from the point I, will be their respective situations on the plan.

To check the accuracy of the work, as well as for extending the survey beyond the limits of vision at I and K, the table may be set up at any one or more of the stations thus determined, as at E: the needle being now fixed in the point E on the board, and the edge of the index placed over E and I (or K,) the table may be moved round till the station I is seen through both the sights, and then clamped firm: the compass will now again, (if all be correct) point out its former bearing, and any lines drawn from E, in the direction of A B C, &c. in succession, will pass through the intersection of the former lines denoting the relative places of those objects on the board; but should this not be the case with all, or any of the lines, it is evident that some error must exist, which can be detected only by setting the instrument up and performing similar operations at other stations.

Having a number of objects laid down upon the plan, the situation of any particular spot, as the bend of a road, &c., may at once be determined, by setting the instrument up at the place, and turning the table about till the compass has the same bearing as at any one of the stations. Clamp the table firm, and it will now be parallel to its former position, if no local attraction prevents the magnetic needle from assuming its natural position at the different stations. Fix a needle in the point representing one of the stations, and resting the edge of the index against it, move the index till the station itself is seen through both the sights, and then draw a line on that part of the paper where the point is likely to fall. Remove the needle to another point or station on the board, and resting the index against it, direct the sights to the corresponding station on the ground, and draw a line along the edge of the index: the point where this line intersects the last, will be the situation on the paper of the place of the magnetic needle, and in that position clamp the table firm. Then, always keeping the fiducial edge of the index against the needle, direct the sights to the other station, K, and by the side of the index draw a line upon the paper, to represent the base, I K; when, if the scale is fixed, the exact length must be laid off, otherwise the point K may be assumed at pleasure on the line so drawn.



But it is sometimes necessary to draw the base line first, whe required, on some particular part of the board, so as to admit o the insertion of a greater portion of the survey. When this i the case, the index must be laid along the line thus drawn, and the table moved till the further end of the base line is see through both the sights; then fix the table in that position, an observe what reading on the compass-card (or bearing) the needl points to, for the purpose of checking the future operations, an also for setting the table parallel to its first position, wherever i may afterwards be set up. It should be observed, that in plac ing it over any station, that spot on the table representing suc station, and not the centre of the table, should be over the st tion on the ground : it may be so placed by dropping a plum line from the corresponding point on the under side of the tabl

Having fixed the instrument and drawn the base line, mov one, a line should be drawn on it, through some particular stations or points of the survey that can be made common to both sheets of paper; then, by drawing a similar line upon the new sheet, and transferring to this line the points or stations that are upon the line in the former sheet, as well as the direction of the ast station lines, the survey may be renewed and continued in the same manner, from sheet to sheet, till the whole is completed. In drawing the corresponding line upon the second sheet, it is necessary to pay due regard to the general direction of the future survey, that the line may be so drawn as to admit the greatest possible quantity of work into each sheet of paper.

Such is the description of the plane-table as formerly, and as now generally constructed; but for our own use we could dispense with the graduations on the box-wood frame altogether, except *perhaps* those of equal parts, which are sometimes useful when shifting the paper. Indeed, in our method of using the instrument, a plain board made of well-seasoned but soft wood (as pine or cedar) to admit readily of a fine pin or needle being fixed in it, would, with the compass-box, answer every purpose; as we should prefer pasting, or gluing, a thick sheet of drawing paper or fine pasteboard over the surface of the table, as the errors caused by changes in the moisture of the air would then be greatly diminished. A fair copy of the plan can be afterwards made out at leisure, and if one board is not sufficient to contain the whole of the survey, others similarly prepared, and adapted to the same staff-head, may be provided, to continue the work.

Having explained the general construction of the instrument, we shall show the manner of using it by means of an example.

In the annexed diagram, let the points marked A B C, &c. be a few of an extensive series of stations, either fixed or temporary, the relative situations of which are required to be laid down upon the plan. Select two stations, as I and K, (considerably distant from each other,) as the extremities of a base line, from which the greatest number of objects are visible; then, if the scale to which the plan is to be drawn is fixed, the distance, I K, must be accurately measured, and laid off upon the board to the required scale; otherwise a line may be assumed to represent that distance; and at some subsequent part of the work the value of the scale thus assumed must be determined, by measuring a line for that purpose, and comparing the measurement, with its length, as represented on the plan.

Set up the instrument at one extremity of the base, suppose supply the place of the theodolite, and an instrument formerly in use called a semicircle. The reverse face of the frame is usually divided into equal parts, as inches and tenths, for the purpose of ruling parallel lines or squares, and for shifting the paper, when the work requires more than one sheet. G is a compass-box, let into one side of the table, with a dove-tail joint, and fastened with a milled-headed screw, that it may be applied or removed at pleasure. The compass, beside rendering the plane-table capable of answering the purpose of a circumferenter, is principally useful in setting the instrument up at a new station parallel to any position that it may have had at a former station, as well as a check upon the progress of the work.

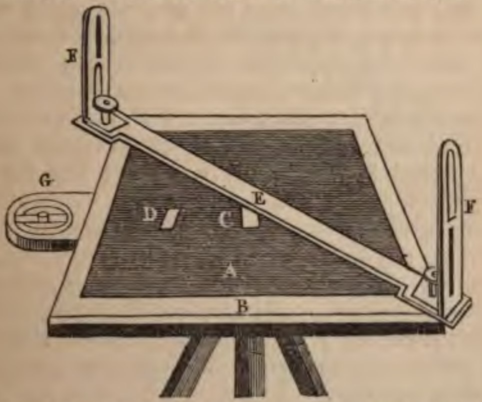
The ruler or index, E, is made of brass, as long as the diagonal of the table, and about two inches broad; it has a sloping edge, liked that of a Gunter's scale, which is called the fiducial edge. A perpendicular sight-vane, F F, is fixed to each extremity of the index, and the eye looking through one of them, the vertical thread in the other is made to bisect any required distant object. Upon the flat surface of the index, there are frequently engraved scales of various kinds, such as lines of equal parts, with diagonal scales, a line of chords, &c.

To the under side of the table, a centre is attached with a ball and socket, or parallel plate-screws like those of the theodolite, by which it can be placed upon a staff-head; and the table may be set horizontal, by means of a circular spirit-level placed upon it for that purpose.

In preparing the plane-table for use, the first thing to be done is to cover it with drawing paper; the usual method of doing which is the same as that of covering a common drawing board, by damping the under side of the paper, and laying it on the board in an expanded state; press the frame into its place, so that the paper may be squeezed in between the frame and the edge of the table; and the paper shrinking as it dries, assumes a flat surface for the work to be performed upon. There is one great objection however to this mode of putting on the paper, as when it has once been damped and strained, it is easily acted upon by any change in the hygrometrical state of the atmosphere. We therefore prefer putting the paper on dry, taking care to keep it straight and smooth whilst pressing the frame into its place; but it must be acknowledged that this cannot be done so nicely as when it is damped. We have been informed, that if the under side of the paper be covered with the white of an egg well beat up, it may be laid on the board with the greatest nicety, and that when so prepared it is not easily affected by atmospheric changes

THE PLANE TABLE.

Before the theodolite came into general use, the Plane-table vas extensively employed in the practice of surveying: it is till sometimes, though seldom, used in surveying small plots of round, or (where great accuracy is not required) in forming a ketch-map, or laying down the details of a country where the elative situations of the principal conspicuous objects have been reviously fixed by triangulation. The expedition with which uch work may be performed, by a person who is expert in the se of this instrument, is its chief recommendation.



The construction and size of the plane table has been varied at different times, to suit both the convenience and intentions of the surveyor; but the annexed figure is a representation of that which is now in most general use. It is a board, as A, about sixteen inches square, having its upper edge rabbetted, to receive a box-wood frame, B, which being accurately fitted, can be placed on the board in any position, with either face upwards. This frame is intended both to stretch and retain the drawing paper upon the board, which it does by being simply pressed down into its place upon the paper, which for this purpose must be cut a little larger than the board.

One face of the frame is divided to 360 degrees, from a centre, C, fixed in the middle of the board, and these are subdivided as minutely as the size of the table will admit. The divisions are frequently numbered each way, to show at sight both an angle and its complement to 360°. There is sometimes a second centre piece, D, fixed on the table, at about a quarter of its width from one of the sides, and at *exactly* half its length in the other direction. From this centre, and on the other side of the frame, illustration, A B represents a portion of the graduated limb an instrument, and C D a portion of the vernier scale, the z point being at C.

Fig. 1.

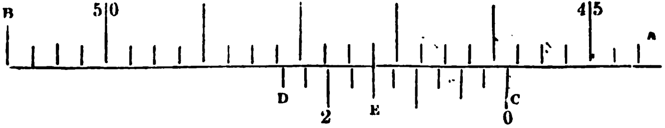


Fig. 2.

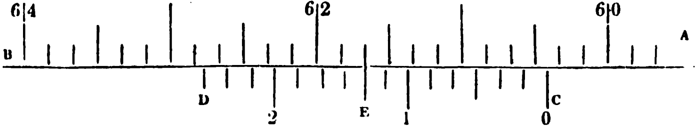


Fig. 3.

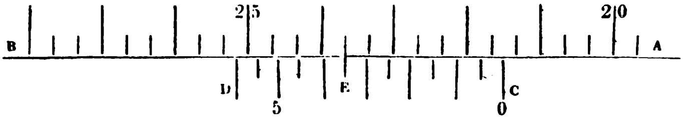
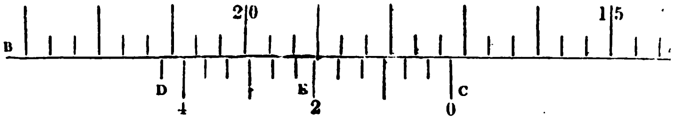


Fig. 4.



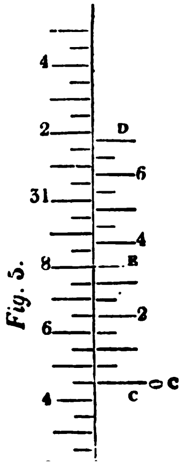


Fig. 5.

In the first figure the limb is divided to and these divisions are subdivided by the nier to 15″. In the second figure, the lim divided to 10′, and subdivided by the ver to 10″. In the third, the limb is divided 20′, and subdivided by the vernier to 30″; in the fourth, the limb is divided to 20′, subdivided by the vernier to 20″. E, on e figure, is placed where a division on the nier coincides with one on the limb. In first, the reading is 45° 46′ 30″; in the seco 60° 21′ 20″; in the third, 21° 23′ 30″; an the fourth, it is 17° 2′, and between 0′ 20″, and as the 2′ line is about as much in vance of the one on the limb near to it, as 20″ line is behind the one near to it, the r ing may be taken as 17° 2′ 10″. The figure represents the scale of a barome coincide with the second, it will be 60° 20′, if with the third, 60° 30′, &c. But when it happens that the zero division of the index does not coincide with any division upon the limb, but stands between two of them, we must observe how many degrees and minutes are denoted by the division it has last passed, and look for a line on the vernier that does coincide with one on the limb; and the number of minutes and seconds from that line to the zero of the index, added to the number read off upon the limb, gives the angle required. Thus, supposing the index to stand between 10′ and 20′ beyond 60°, and the line on the vernier denoting 6′ 10″ (which is the line next beyond the one marked 6) coincides with any one on the limb, then this quantity, added to 60° 10′, gives 60° 16′ 10″, the angle required.

When the arc of excess on the limb of the sextant (the nature of which will be explained hereafter) is required to be read off, observe what quantity is passed to the right of zero by the zero division of the vernier, and find the remaining minutes and seconds to be added to it, by reading the vernier backwards; that is, consider the last numbered division to the left hand as the zero: thus, suppose that (on our instrument) the index stood beyond the third short division on the arc of excess, this would be 30′, and if the third long division from the last numbered one on the left hand (marked 10,) coincided with a line on the limb, this would denote 3′ to be added to the former, making 33′ for the reading on the arc of excess.

On the limbs of small theodolites, the spaces between the degrees are generally divided into two parts, consequently the short division represents 30′, and the divisions on the vernier are single minutes; a smaller subdivision must be estimated by the eye, which by a person accustomed to the instrument can be done to 15″.

The subdivision of a straight line, as the scale of a mountain barometer, is likewise effected by a vernier, and is read off in the following manner. The scale is divided into inches, which are subdivided into 10 parts; these tenths are again divided into two, by a shorter division, which will be 5 hundredths of an inch. The long divisions upon the vernier show each of them one hundredth of an inch, and they are numbered at every fifth; these are again subdivided by shorter lines, representing thousandths. Now, to read it off, observe where the zero division of the vernier stands on the scale; suppose a little above 30 inches and 4 tenths, and as it does not reach the short line denoting 5 hundredths, observe what line on the vernier coincides with one on the scale: if it is a long division, then it is so many hundredths to be added, and if a short division, it tenths of an inch, and divided into 10 equal parts; for in either case the difference between the divisions of the scale so made and those on the primary scale is the hundredth of an inch. Such a scale made to move along the edge of that to be subdivided is called a vernier; and we shall explain how by its application, either to straight lines or arcs of circles, the subdivisions of graduated instruments are read off. For this purpose, let us take as a general example the method of reading the sextant, as a person acquainted with the graduations upon this instrument will find no difficulty in becoming familiar with those on any other.

It will be observed,* that some of the divisional lines on the limb of the instrument are longer than others, and that they are numbered at every fifth, thus, 0. 5. 10. 15, &c., the 0 being the starting point, or zero. The spaces between these lines represent degrees; and they are again subdivided by shorter lines, each smaller space representing a certain number of minutes. For instance, if the spaces are subdivided into four parts, then there will be three short lines, each of which will indicate the termination of a space of 15 minutes; if there are six parts, there will be five short lines, and each will be at the end of a space of 10 minutes, reckoned from the commencement of the divisions. Likewise it will be observed, that some of the divisions on the vernier are longer than others: these indicate in the same manner single minutes, and they are numbered from right to left: the extreme right one is the zero, or commencement of the index divisions, and it is marked 0 or ◊; the shorter divisions show fractions of minutes. If the spaces between each minute (or long division) contain three lines, each space will be 15 seconds, and if five, 10 seconds; the number of subdivisions between the minutes of the vernier is usually, but not necessarily, the same as between the degrees on the limb, so that if the limb is divided into 20′ the vernier is divided into 20″; if the former is divided to 10′ the latter is divided to 10″, &c.

The limb of the instrument now before us is divided to 10′, and the vernier reads to 10″, and by showing the manner of reading it off, we shall explain sufficiently the method of reading verniers in general. If the zero division of the vernier coincide (or form a straight line) with any line on the limb, then that line indicates the required angle; thus, if it coincide with the line marked 60, then sixty degrees is the angle; if with the next long division, then 61 degrees will be the angle; but if it coincide with one of the shorter lines between 60 and 61, then the angle will be 60 degrees and a certain number of minutes, according to which of the short lines it coincides with. If it be the first the coloured glasses represented at G, are intended for that purpose; the joint upon which they act, allowing them to be turned down over the sloping side of the prism-box.

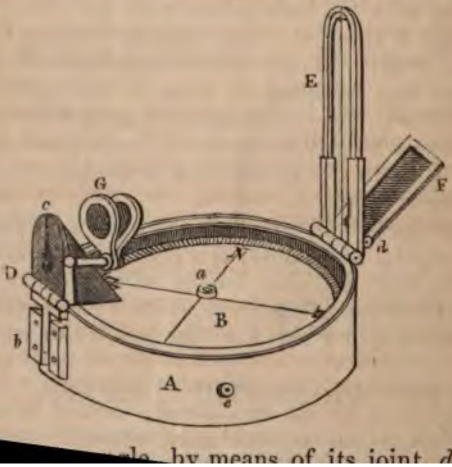
At *e*, is shown a spring, which being pressed by the finger at the time of observation, and then released, checks the vibrations of the card, and brings it more speedily to rest. A stop is likewise fixed at the other side of the box, by which the needle may be thrown off its centre; which should always be done when the instrument is not in use, as the constant playing of the needle would wear the point upon which it is balanced, and upon the fineness of the point much of the accuracy of the instrument depends. A cover is adapted to the box, and the whole is packed in a leather case, which may be carried in the pocket without inconvenience.

The method of using this instrument is very simple. First raise the prism in its socket, *b*, until you obtain distinct vision of the divisions on the card, and standing at the place where the angles are to be taken, hold the instrument to the eye, and looking through the slit, *c*, turn round till the thread in the sight-vane bisects one of the objects whose azimuth, or angular distance from any other object, is required; then, by touching the spring, *e*, bring the needle to rest, and the division on the card which coincides with the thread on the vane, will be the azimuth or bearing of the object from the north or south points of the magnetic meridian. Then turn to any other object and repeat the operation; the difference between the bearing of this object and that of the former, will be the angular distance of the objects in question. Suppose the former bearing to be 40° 30′ and the latter 10° 15′, both east, or both west, from the north or south, the angle will be 30° 15′. The divisions are generally numbered 5°, 10°, 15°, &c. round the circle to 360°. A tripod stand similar to those of the theodolite described at page 15, can be had with the instrument, if required, on which to place it when observing, instead of holding it in the hand.

THE VERNIER.

This is a contrivance for measuring parts of the space between the equidistant divisions of a graduated scale. It is a scale whose length is equal to a certain number of parts of that to be subdivided, depending on the degree of minuteness to which the subdivision is intended to be carried; but it is divided into parts, which in number are one more or one less than those of the primary scale taken for the length of the vernier: in modern practice the parts on the vernier are generally one more than are contained in the same space on the primary scale survey. It may likewise be used for determining approximately the direction of the true meridian, the variation being determined by comparing the observed azimuth of a celestial object, with its true azimuth deduced from an observation made for the purpose.

In the following figure, A represents the compass-box, and B the card, which being attached to the magnetic needle, moves as *it* moves, round the agate centre, *a*, on which it is suspended. The circumference of the card is usually divided to 15′ of a degree, but it is doubtful whether an angle can be measured by it even to that degree of accuracy: *c* is a prism, which the observer looks through in observing with the instrument. The perpendicular thread of the sight-vane, E, and the divisions on the card appear *together* on looking through the prism, and the division with which the thread coincides, when the needle is at rest, is the magnetic azimuth of whatever object the thread may bisect. The prism is mounted with a hinge joint, D, by which it can be turned over to the side of the compass-box, that being its position when put into the case. The sight-vane has a fine thread stretched along its opening, in the direction of its length, which is brought to bisect any object, by turning the box round horizontally; the vane also turns upon a hinge joint, and can be laid flat upon the box, for the convenience of carriage. F is a mirror, made to slide on or off the sight-vane, E; and it may be reversed at pleasure, that is, turned face downwards; it can also



by means of its joint, *d*; and it

being the hypothenuse, and the horizontal line the base ; or it may be more expeditiously accomplished by our Table IX. which shows the quantity to be subtracted from each chain's length for various angles of inclination of the ground, which at once reduces the oblique or hypothenusal measure, to the horizontal.

THE SURVEYING CROSS AND OPTICAL SQUARE.

The instrument formerly employed for laying out perpendicular lines, was the cross-staff, of which there were various constructions; but that in most general use consisted of four sights, fixed at right angles upon a brass cross, and adapted to the top of a staff; which being thrust into the ground with two of the sights placed in any given direction, the other two pointed out the perpendicular required. But this instrument has been almost superseded by the optical square, which is much superior to it both for convenience and expedition; and it has also the advantage of greater portability, not being larger than a shallow circular snuff-box, which it resembles in shape. It is made of brass and contains the two principal glasses of the sextant, viz., the index and horizon glasses, fixed at an angle of 45° ; hence, while viewing an object by direct vision, any other, forming a right angle with it, at the place of the observer, will be referred by reflection, so as to coincide with the object viewed. Thus a line may be laid out perpendicular to a station-line, and from any point on it, by simply standing with the instrument over the given point, and looking through it along the line, having a person to go with a mark or station-staff in the direction the perpendicular is required, and signing to him by hand to move to the right or the left, until his staff is seen by reflection to coincide with some object on the line along which the observer is looking, when the place of the staff will be in a perpendicular to the station-line at the place of the observer.

If it be required to find on a line the place of a perpendicular from a fixed object, as a house, &c. the observer himself must move along the line until the image of the object appears, as before, in the direction of the line, and the place where he then stands, will be the spot where such perpendicular would fall.

THE PRISMATIC COMPASS.

The use of this little instrument is to measure horizontal angles only, and from its portability is particularly adapted for military surveying, or where but little more than a *sketch map* of the country is required. It is also very useful in filling in the detail

The operation of measuring with the chain requires at least two persons, one to lead and the other to follow and direct, the first or leader (taking the ring at one end of the chain upon two fingers of his right hand with one arrow, and the remaining nine in his left,) lays his end of the chain, by direction of the follower, in a straight line with the station to be measured to, and there fixes an arrow, while the latter holds the other end of the chain at the starting point; the leader now proceeds onwards until the follower comes to the arrow first laid down, to which he places his end of the chain, and again directs the leader to place a second arrow in line with the forward station: the leader will now have an opportunity of checking the directions of the follower at every succeeding chain's length, by observing if the latter is also in a line with the back station, at the time he directs him to place one of his arrows in the direction of the forward station: they proceed in this manner till the whole line is measured, or the leader has spent all his ten arrows, which, upon counting, he will find in the possession of the follower, (unless some error has been committed,) who must restore them to the leader, and remark in the field-book that they had made one change, or measured 1000 links; they then proceed onwards as before, the leader taking all the ten arrows, until they are again spent, when a second change must be made and entered in the book, and if the line is measured out before a third change takes place, the follower will have in his hand as many arrows as there have been chains laid out upon the last measured part of the distance; which, together with the odd links and the former two changes (or 2000), will make up the entire length of the line.

For the purposes of plotting, &c. it will be necessary to reduce the measurement of the lines which alternately ascend and descend to the correct horizontal measure, for it is evident that the distance between two points, if measured over uneven ground, will be greater than if measured perfectly straight in a horizontal plane. Some surveyors attempt this correction as they proceed, by holding the lower end of the chain above the ground, as nearly horizontal as they can estimate, and if they aim at considerable accuracy, will have a plumb, which they allow to hang from the hand that holds the chain, over the arrow or mark in the ground. In passing over very steep ground, they frequently take half or even a quarter of a chain's length to accomplish their measurements with, as the whole length would be too great to be held horizontal, when the inclination is considerable. But the most correct method is to take the vertical angles along the undulations of the line after it has been mea-

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